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1961-62

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Applications in Chemistry of Properties Involving Molecular Polarisability*

R. J. W. LE FÈVRE†

Introduction

Mr. President, Ladies and Gentlemen,

Before saying anything else I want to thank the Council of the Royal Society of New South Wales for the honour they have conferred on me by the invitation to give this lecture. I am especially appreciative because I am the first of Liversidge's successors to be so favoured. After nearly fourteen years in Australia my admiration of the part which Archibald Liversidge quietly took in the chemical and scientific life of this country and this University continues to grow. His achievements have been recorded by Sir Edgeworth David in 1931 and, more recently, by Professor Mellor in 1957; between the lines one can feel the difficulties, the "limitations and misunderstandings", against which he worked, yet he built a new chemistry department here, supported the introduction of women students, persuaded the University to set up a Faculty of Science (of which he became first Dean), was prominent in the inauguration of technical education in N.S.W., was a founder of A.N.Z.A.A.S., was a reviver and supporter of this Society, and was active in researches on chemical mineralogy, on the origin and precipitation of gold, on the compositions of rocks and ores and meteorites—researches of peculiar appropriateness to the Australia of his day.

Mellor says: "In some ways Liversidge was ahead of his time." Perhaps he foresaw how chemistry would change and expand. By his Will he founded this Research Lectureship, and three others for a similar purpose elsewhere. His directions show his far-sightedness: the "lectures are to be open to the public (free or at a nominal fee), but are not to be popular lectures nor such as are intended for the ordinary lecture room instruction of undergraduates, but

shall be such as will primarily encourage research and stimulate the lecturer and the public to think and acquire new knowledge by research instead of merely giving instruction in what is already known". In satisfaction of these terms, previous Liversidge Lecturers have usually selected subjects with which they themselves are personally connected. I propose to do likewise.

Genesis of the Subject—As a young organic chemist in England during the late 1920's, I saw and heard a great deal of the then developing theoretical approaches to reactivity and reaction mechanism associated particularly with the names of Robinson and Ingold—approaches which fundamentally involved the concepts of permanent and temporary polarity, that is, of polarisation and polarisability, and their influences on and within molecules. The physical measurement of the former I took up partly from stereochemical motives and partly as a contribution to quantitative knowledge of the "inductive" and "mesomeric" effects. Much less was known of the "tautomeric" or "inductomeric" polarisability effects; accordingly, a few years before the last war, my wife and I decided to attempt their direct investigation. This necessitated the practical measurement of electric double refraction and thus brought us into contact with a physical property which, during our period in Australia, has been developed into stereochemical usefulness, and which is now beginning to be applied by others elsewhere in the world.

The Anisotropy of Molecular Polarisability

Nearly all molecules are anisotropically polarisable under an electric field. The degree of such anisotropy is sensitively connected with molecular structure, conformation, and morphology; its measurement and interpretation are therefore the basis of the developments just mentioned.

* Liversidge Research Lecture delivered before the Royal Society of New South Wales, October 13th, 1960.

† Professor R. J. W. Le Fèvre, F.A.A., F.R.S., Head of the Chemistry School, University of Sydney.

When an electric field of unit strength acts upon a molecule the dipole moment induced is, by definition, the polarisability b of the molecule. With spherically symmetrical molecules the directions of action of b and of the field will be always collinear; with less symmetrical molecules the induced moment will usually be at angles to the field depending on the orientations of the molecule in the field—in other words,

$${}_mK = 6Bn\lambda M/(\epsilon + 2)^2(n^2 + 2)^2d$$

$$\text{and } \delta^2 = 10\Delta/(6 - 7\Delta)$$

$$= [(b_1 - b_2)^2 + (b_2 - b_3)^2 + (b_3 - b_1)^2]/(b_1 + b_2 + b_3)^2$$

(Δ =depolarisation factor,

n =refractive index,

ϵ =dielectric constant,

d =density,

M =molecular weight),

may be measured for solutions at infinite dilution. (The "molar Kerr constant" of a substance can be visualized as the differences of its molecular refractions parallel and perpendicular to a unit electric field in the Kerr cell.)

From the extrapolated molar Kerr constant $\infty({}_mK_2)$ and the electronic polarisation ${}_EP$ of a solute, we have, at 25°C,

$$\theta_1 + \theta_2 = 0.2378 \times 10^{-23} \times \infty({}_mK_2)$$

and

$$b_1 + b_2 + b^e = 0.11891 \times 10^{-23} \times {}_EP.$$

Several hundred $\infty({}_mK_2)$'s have now been recorded (mostly in the *Journ. Chem. Soc.*) by the Le Fèvres and their collaborators, and from the majority the related principal polarisabilities calculated.

Principal Molecular Polarisabilities and Bond Polarisabilities

The data thus accumulated have further been analysed in terms of anisotropic bond polarisabilities. A suggestion that bonds may have different polarisabilities along their lengths and in the two perpendicular transverse directions was first made qualitatively in 1931 by

Meyer and Otterbein. Representing these as b_L^{XY} , b_T^{XY} and b_V^{XY} (L =longitudinal, T =transverse, and V =vertical) for the bond joining the atoms X and Y , we have e.g. for the molecule XY_2 where the angle YXY is 2θ :

$$b_1^{XY_2} = 2(b_L^{XY} \cos^2 \theta + b_T^{XY} \sin^2 \theta),$$

$$b_2^{XY_2} = 2(b_L^{XY} \sin^2 \theta + b_T^{XY} \cos^2 \theta),$$

and

$$b_3^{XY_2} = 2b_V^{XY}.$$

the field will induce component moments parallel and perpendicular to itself. Only for certain clearly definable orientations will these perpendicular components be zero. In the case of a completely unsymmetrical molecule there will be three such orientations, mutually at right angles, and the moments induced parallel with the field in each situation are known as the principal polarisabilities b_1 , b_2 , and b_3 of the molecule.

These polarisabilities enter the mathematical treatments accorded by Langevin, Gans, Born, Debye and others to many optical and electrical phenomena, and in particular to refractivity, light scattering, dielectric polarisation and the Kerr effect. For a given molecule, b_1 , b_2 and b_3 are therefore accessible from quantitative measurements associated with the phenomena named. Details are given in a review by Le Fèvre and Le Fèvre (1955). Thus the total $(b_1 + b_2 + b_3)$ comes from molecular refractions, the squares of the differences

$$(b_1 - b_2)^2 + (b_2 - b_3)^2 + (b_3 - b_1)^2$$

from depolarisation factors in Rayleigh scattered light, and a sum $(\theta_1 + \theta_2)$ from the observed Kerr constant B (defined as $(n_p - n_s)/\lambda E^2$, where n_p and n_s are the refractive indices of a dielectric parallel and perpendicular to the lines of force of a field E , for light of wavelength λ). Expansions of θ_1 and θ_2 are:

$$\theta_1 = [(b_1 - b_2)^2 + (b_2 - b_3)^2 + (b_3 - b_1)^2] {}_dP / 45kT({}_EP)$$

$$\theta_2 = [(b_1 - b_2)(\mu_1^2 - \mu_2^2) + (b_2 - b_3)(\mu_2^2 - \mu_3^2) + (b_3 - b_1)(\mu_3^2 - \mu_1^2)] / 45k^2T^2$$

(μ_1 , μ_2 , and μ_3 being the resolute of the resultant molecular moment along the directions in which b_1 , b_2 , and b_3 are measured, and ${}_dP$ and ${}_EP$ the distortion and electronic polarisations respectively).

Application to Solutes—The underlying theory upon which these formulae are based applies strictly to dielectrics as gases—a state into which many interesting substances cannot be brought without decomposition and in which

In many instances the calculations are simplified by the facts that $b_2=b_3$ or $b_1=b_2$, or $b_T^{XY}=b_V^{XY}$, etc. By application to molecules of known structure of the type of argument illustrated by this simple example, the polarisabilities of the commoner bonds entering organic molecules have been deduced. They are listed in Table 1.

TABLE 1

Bond	$10^{23}b_1$	$10^{23}b_2$	$10^{23}b_3$	Bond environment
C-H	0.064	0.064	0.064	Paraffin hydrocarbons
C-C	0.098 ₆	0.027 ₄	0.027 ₄	cycloHexane
„	0.097 ₉	0.027 ₂	0.027 ₂	cycloPentane
C-F	0.12 ₅	0.04	0.04	CH ₃ F
„	(0.07)	(0.07)	(0.03)	C ₆ H ₅ F
C-Cl	0.31 ₈	0.22	0.22	CH ₃ Cl
„	0.39 ₅	0.16	0.16	(CH ₃) ₃ CCl
„	0.399	0.185	0.185	CCl ₄ and CHCl ₃
„	0.382	0.185	0.185	cyclo-C ₆ H ₁₁ Cl
„	0.42	0.19 ₅	0.15	C ₆ H ₅ Cl
C-Br	0.46 ₆	0.31	0.31	CH ₃ Br
„	0.60	0.26	0.26	(CH ₃) ₃ CBr
„	0.53	0.27	0.27	cyclo-C ₆ H ₁₁ Br
„	0.62	0.24	0.22	C ₆ H ₅ Br
C-I	0.68	0.47	0.47	CH ₃ I
„	0.88	0.42	0.42	(CH ₃) ₃ CI
„	0.80 ₇	0.41 ₈	0.41 ₈	cyclo-C ₆ H ₁₁ I
„	0.91	0.53	0.33	C ₆ H ₅ I
C=C	0.280	0.073	0.077	CH ₂ =CCl ₂
C≡C	0.35	0.13	0.13	C ₂ H ₂
C-O	0.081	0.039	0.039	Paraldehyde
C=O	0.230	0.140	0.046	(CH ₃) ₂ C=O
N-H	0.050	0.083	0.083	NH ₃
N-C	0.057	0.069	0.069	(CH ₃) ₃ N
CAr-CAr	(0.224)	(0.021)	0.059	C ₆ H ₆

As is to be expected, the anisotropy of a given bond is not a "universal" constant but appears to be somewhat affected by the structural environment; such becomes notably the case when double bonds are in conjugation—signs of this can be seen in the data for the aryl halides, and will often be found for links in molecules markedly exhibiting exaltations of refractivity. Perhaps part of the inconstancy is due to the incorporation into the listed values of "secondary polarisabilities"—the augmentations or diminutions caused mutually by two induced moments in proximity to one another and varying with their orientations; *a priori* estimations of such effects by the formulae of

electrostatics, however, are often tediously long and always involve the unknown dielectric constant of inter-atomic space. Yet another cause could be the inclusion in bond polarisabilities of part of the polarisabilities of adjacent lone-pair orbitals—this may explain why the H-N and C-N bonds appear to have b_L less than b_T . A safe view-point is that the data in Table 1 are empirical and should be useful in situations analogous to those from which they have come.

Polarisability in Relation to Molecular Structure

The application of bond polarisabilities to problems involving choices of structures or conformations is straight-forward. In each of the various alternative models a convenient set of rectangular axes, x , y and z is set. One first imagines a unit field acting e.g. along x , and computes the moments b_{xx} , b_{yx} , and b_{zx} which it induces in the x , y and z directions; next the process is repeated for the field along the y , and finally along the z axis. Solution of the cubic equation in λ

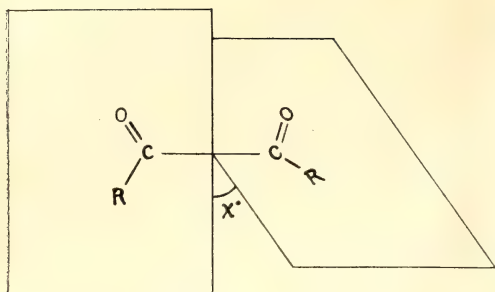
$$\begin{vmatrix} (b_{xx}-\lambda) & b_{xy} & b_{xz} \\ b_{yx} & (b_{yy}-\lambda) & b_{yz} \\ b_{zx} & b_{zy} & (b_{zz}-\lambda) \end{vmatrix} = 0$$

then yields the required principal polarisabilities, b_1 , b_2 and b_3 , for the structure under consideration, and permits the calculation of the direction cosines which locate these b 's in the axes taken.

When b_1 , b_2 , and b_3 are available from experiment, comparison can be made directly. In other cases the b 's may be used in conjunction with the observed dipole moment to predict the appropriate molar Kerr constants, which are then compared with the measured $\infty(mK_2)$. In many instances the correct model is at once obvious.

Some Specific Applications

A few qualitative and quantitative applications of polarisability to questions of molecular space-formulation were described by Le Fèvre and Le Fèvre in their 1955 *Review*. Further evidence bearing on some of these has since come forward. The skew structure assigned to benzil, because its Kerr effect was algebraically negative, is now substantiated by work recently completed by Miss P. Cureton, whose experiments show incidentally that the related diketones, furil and diacetyl, are also best represented by skew formulae:

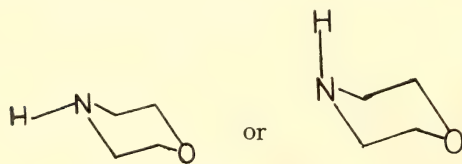


R	Me	C ₆ H ₅	C ₄ H ₃ O
χ°	156°	97°	121°
$10^{12} {}_m K_{\text{calc.}}$	-37	-664	-627
$10^{12} {}_m K_{\text{obsd.}}$	-28	-664	-627

In such instances, of course, the resultant dipole moment varies with the azimuthal angle, χ° , so that in principle at least the degree of non-planarity could be determined from the polarity.

Considerations involving the anisotropy of polarisability are most useful when the choice to be made is between several configurations any one of which may be expected to have a resultant dipole moment indistinguishable from or closely similar to those of the others. Three examples of this type will be cited.

The first concerns the molecule morpholine for which theoretically a number of "boat" and "chair" structures can be written. Aroney and Le Fèvre (1958) showed that all but two can be dismissed because neither their calculated dipole moments nor their calculated molar Kerr constants approached the values from actual measurement (*viz.* 1.5₄D. and -24.3 × 10⁻¹² respectively). The choice lay therefore between the two representations



$$10^{12} {}_m K_{\text{calc.}} = +14.1 \quad \text{or} \quad -26.2$$

$$\mu_{\text{calc.}} = 1.5_1 \text{D} \quad \text{or} \quad 1.5_1 \text{D.}$$

and the clear-cut conclusion was that morpholine exists, as a solute, almost wholly as the conformation with the N-H link disposed *axially*.

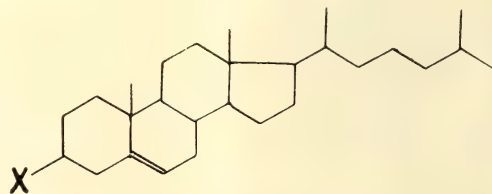
The second example concerns the related problem among the *cyclohexyl*-halides. Le Fèvre and Le Fèvre first dealt with the matter in 1956, reporting that *cyclohexyl*-chloride, bromide, and iodide appeared to have their

halogens attached predominantly equatorially. Improved calculations (based on more appropriate C-X link polarisability data) published recently (Le Fèvre, Le Fèvre, Roper and Pierens, 1960) for the principal polarisabilities of the equatorial and axial isomers of C₆H₁₁X, together with the location of the directions of action of the molecular dipole moments within the framework defined by the coordinates along which *b*₁, *b*₂, or *b*₃ are measured, give the following results:

X in C ₆ H ₁₁ X	Attachment of C-X bond	$10^{12} {}_m K_{\text{calc.}}$	$10^{12} \infty ({}_m K_2)$ observed in carbon tetrachloride
Cl	axial	51	122
	equatorial	154	
Br	axial	111	181
	equatorial	226	
I	axial	179	249
	equatorial	291	

Since ${}_m K$ observed for a mixture should be additively related to the ${}_m K$'s of the components, the implication is that at infinite dilution in carbon tetrachloride these halides exist *ca.* 70%, 60%, and 60% respectively in their equatorial form. By different techniques (kinetic studies, N.M.R. and infra-red spectra) and in other media, equatorial:axial ratios lying between 3:2 and 5:1 have been reported. The matter deserves further investigation, especially from the viewpoints of solvent and temperature effects.

The third example resembles the second but is advanced because the carbon skeleton involved belongs to the important natural class of steroids. When X=OH the adjoining formula



is that of cholesterol; we have examined *inter alia* cholesteryl chloride, bromide, and iodide, and cholestenone (in which C₃ is the carbon of a ketone group). A practical difficulty needed to be removed as a preliminary: measurements of the Kerr effect are normally made in polarised light between Nicol prisms crossed for *extinction*, so that the introduction of molecules having natural optical rotatory powers prevents this condition being attained. Mr. J. M. Eckert

has shown, however, that errors caused thereby diminish steadily as the concentrations (in benzene, carbon tetrachloride, etc.) of the active solute are reduced; accordingly, by a process of extrapolation the electric birefringence due to the solute can be deduced at infinite dilution. (As a check, the molar Kerr constants at infinite dilution found for a number of optical antipodes and for their corresponding (\pm) forms have been demonstrated as the same within the ordinary limits of experimental errors.)

With the cholesteryl halides our objective was to ascertain whether the links C-X were "equatorial" or "axial". As a guide to the inter-valency angles in the $C_{27}H_{45}$ -radical the X-ray analysis of cholesteryl iodide by Carlisle and Crawford (1945) has been invoked, and two treatments given the data thus available: (a) a scale-model built to show the locations of the numerous atom-centres and centre-centre links, and (b) direction cosines for all the anisotropically polarisable bonds calculated from Cartesian coordinates, computed in turn from position coordinates obtained by multiplying Carlisle and Crawford's fractional coordinates by the appropriate unit cell dimensions.

By "trial and error"—by stretching threads through the model and directly measuring angles between thread and bonds—the axes of maximum and minimum polarisability were sought empirically; later the full and lengthy calculation of the polarisability matrix (as described formally above) has been undertaken, using the SILLIAC machine in the School of Physics to solve the final cubic equation, to give the desired principal polarisabilities, and the nine direction cosines required to define their dispositions in space. Values of b_1 , b_2 , and b_3 by the two methods agree to within 1%, although the angles between C-X and b_1 differ by 8°, 6°, and 4° for the chloride, bromide, and iodide respectively (being 6° throughout when measured manually).

At the present stage the analysis is as follows:

Solute	$10^{12} mK$		
	Calc. equatorial	Calc. axial	observed
Cholesteryl chloride	$\left\{ \begin{array}{l} 360 \text{ (manual)} \\ 306 \text{ (SILLIAC)} \end{array} \right\}$	—88.0	+435
bromide	$\left\{ \begin{array}{l} 447 \text{ (manual)} \\ 384 \text{ (SILLIAC)} \end{array} \right\}$	—50.9	+492
iodide	$\left\{ \begin{array}{l} 532 \text{ (manual)} \\ 462 \text{ (SILLIAC)} \end{array} \right\}$	+4.1	+517
Δ^5 -Cholestenone	+280 (calc.)		+282
Δ^5 -Cholestene*	+42 (calc.)		+44

* Now under examination by Mrs. S. Alamelu.

It is seen that in the three halides equatorially disposed C-X bonds are indicated very strongly, although the observed molar Kerr constants exceed those calculated by 10–25%. Reasons for the discrepancy are not clear. These molecules are the largest so far studied, they contain more than 70 bonds, so that small inadequacies in the polarisabilities of these will be summed up in the calculation of the molecular polarisabilities; moreover we may here be dealing with cases where neglected secondary effects—the polarisation induced in one link affecting that induced in its neighbours—are accumulating and becoming noticeable (yet the calc. and obsd. mK 's for Δ^5 -cholestenone and Δ^5 -cholestene are most satisfactory).

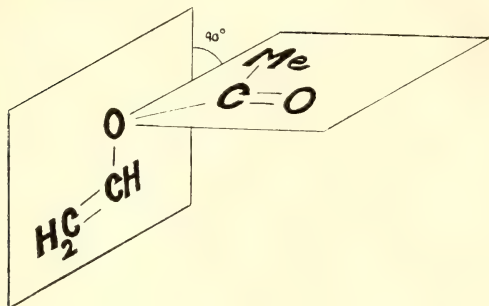
Finally, we have no evidence that a $C_{27}H_{45}X$ molecule *in solution* will be identical with cholesteryl iodide *in the crystalline state*. An analogous assumption would be misleading in certain other cases, e.g. dimethyl oxalate, diethyl terephthalate, 1,2-dibromoethane, and 1,4-dimethoxybenzene are all reported to be *trans*-forms in the solid phase (*Chem. Soc. Special Pubn.* No. 11, 1958), but their non-zero dipole moments as solutes demonstrate that they are not thus present in solution.

Nevertheless, despite the imperfections mentioned, we submit this work as the first to display the conformation at C_3 of dissolved cholesteryl halides without using arguments of analogy.

Other Conformational Studies Recently Published or in Progress

Time will not permit an extensive discussion of further examples. Clearly the method is suitable for the investigation of the "apparent" or "average" configuration adopted by a flexible or easily distorted solute molecule. Cases of this type described in recent publications include the polystyrenes, polyvinylacetates, and polyethyleneglycols (with Miss G. M. Parkins and my wife, 1958 and 1960), various trialkylamines, arylamines, hydrazines, piperidines, piperazines, phenylene diamines, etc. (with M. Aroney, 1960), most of the *n*-alcohols up to octadecyl (with C. G. Le Fèvre, B. Purnachandra Rao, and A. J. Williams, 1960), neopentyl halides (with C. G. Le Fèvre and M. R. Smith, 1958), azodiformates, maleates and fumarates (with C. G. Le Fèvre and W. T. Oh, 1957), cycloheptanone and other *cyclic*-ketones (with C. G. Le Fèvre and B. Purnachandra Rao, 1959), substituted diphenyls (with C. G. Le Fèvre and J. Y. H. Chau, 1959), and the mono- and

di-methoxy-, -acetoxy-, and -carbethoxy-benzenes (with M. Aroney and Shu-Sing Chang, 1960). In many of these instances our measurements have indicated the existence of several conformations, usually foreseeable by inspection of scale-models showing van der Waals radii and thus steric hindrances. An interesting case where results can be explained with a single form is monomeric vinyl acetate, ${}_mK$ obsd. for which is 3.6×10^{-12} , versus values ranging from $30-118 \times 10^{-12}$ for the various planar forms ;



$$\begin{aligned} {}_mK_{\text{obs.}} &= 3.6 \times 10^{-12} \\ {}_mK_{\text{calc.}} &= 4.9 \times 10^{-12} \end{aligned}$$

here the vinyl-group seems to be conveniently oriented to obviate the acetoxy-radicals impeding the growth of the carbon chains during addition polymerisation.

Other studies now in hand concern trialkyl borates (M. Aroney and P. M. Lenthen), alkyl nitrites (K. D. Steel), monohalogeno-alkanes (A. J. Williams), α : ω -dihalogeno- and dicar-bethoxy-alkanes (M. Aroney and D. Izsak), anils and azo-compounds (R. S. Armstrong and N. Hackett), the di-*n*-alkyl ketones (M. Aroney and D. Izsak), isomeric oximes (N. Hackett), tropinone (J. M. Eckert), Tröger's base (M. Aroney and L. H. L. Chia), many aliphatic and aromatic hydrocarbons including rubber and gutta-percha, squalene, and other polyisoprenoids (S. Alamelu and K. M. Somasundaram), etc. The objective of all these is conformational information.

Time allows only a mention of a widening of technique now proceeding in our laboratories. By the imposition of several kilovolts, suddenly and only for fractions of a microsecond, to a solution under examination we should be able to measure Kerr effects with conducting media, and also—with natural macromolecules such as proteins—to estimate rotary diffusion constants, and hence length-diameter ratios for the solute particles concerned. Mr. Steel is developing the

necessary equipment, and is intending to gather experience by an exploration of the warm-water induced reaction: collagen \rightarrow gelatine. In the hope that we shall later be able to handle, *inter alia*, nucleic acids by such methods, preliminary work by conventional procedures has been started on phosphate esters (L. H. L. Chia) and P-O bonds (N. Hackett), on a few purine derivatives (Miss P. Cureton), and on certain alkylated and acetylated sugars (J. M. Eckert). Macromolecular morphology is here the ultimate objective . . . many difficulties lie ahead, and the first is not the least: to make reliable electric double refraction observations in aqueous media; afterwards will come the problems of interpretation!

The Anisotropy of Polarisability in Conjugated Systems

That exaltations of mean polarisability occur in conjugated systems has been recognized for years through the imperfect additivity shown by their molecular refractions, R . ($R_{\text{expt.}} - R_{\text{calc.}} = \Delta R = \text{exaltation.}$) It was not known, however, whether these polarisability increments occurred uniformly (isotropically) within a molecule, or preferentially (anisotropically) in particular directions. Information on the matter is obviously necessary if the fullest stereochemical use is to be made, along lines illustrated above, of polarisability as an anisotropic molecular property, calculable from the related anisotropic bond properties.

Le Fèvre and Le Fèvre first attacked the problem, as it related to substituted benzenes, in 1954. By subtracting from the principal polarisabilities found by experiment for $\text{C}_6\text{H}_5\text{X}$ and CH_3X the corresponding polarisabilities of C_6H_5 (i.e. benzene minus C-H) and CH_3 (i.e. methane minus C-H), b_L^{C-X} , b_T^{C-X} and b_V^{C-X} values for the C-X bond in the two situations were obtained. The differences, $(b_i^{CX})_{\text{aryl}}$ minus $(b_i^{CX})_{\text{aliphyl}}$, where $i=1, 2$, or 3 , suggested that the exaltations of polarisability produced by substituents in aromatic combination were concentrated along those directions in which electromeric or hyperconjugative electronic displacements could be expected by organochemical theory; for the halogeno-benzenes this direction is coincident with μ_{C-X} , i.e. the exaltation predominantly affects b_1 , often apparently at the expense of b_2 and b_3 (cf. Le Fèvre and Purnachandra Rao, 1958).

Exaltations among benzene derivatives are, however, rather small; they are much larger with open-chain conjugated systems. Examples

of the latter type, recently studied by Bramley and Le Fèvre (1960), are the $\alpha:w$ -diphenylpolyenes, $C_6H_5 \cdot (CH=CH)_n \cdot C_6H_5$, in which $n=1$ to 4. These materials display exaltations of mean polarisability, respectively, for $n=1, 2, 3$, and 4, of ca. $0.25, 0.59, 0.96$ and 1.53×10^{-23} c.c.; their measured molar Kerr constants rise roughly by $10^{12} mK = 41 + 79n^2$, where 41 is the value for biphenyl ($n=0$).

Of course, such molecules are probably mesomerides in which the $C=C$ bonds lose their identities by mesomeric shifts of the kind $C=C-C=C$, their π -electrons becoming part of a delocalized system. Nevertheless an analysis in which the exaltation of polarisability due to conjugation is separated from the polarisability of an "isolated" $C=C$ bond, although perhaps unjustifiable by theory, enables us to retain the procedure of adding bond polarisabilities tensorially, and thereby to forecast mK 's in reasonable accord with those actually measured.

We first calculate b_1^* , b_2^* and b_3^* , without allowance for conjugation, using the geometrical specifications established by X-rays for these polyenes. Then, utilising the conclusion reached with the benzene derivatives, we add the exaltation of polarisability along that direction in which mesomerism is most to be expected. Finally, we recalculate b_1 , b_2 and b_3 as the maximum, intermediate, and minimum polarisabilities respectively for the real structure; from these, and for comparison with experiment, the molar Kerr constants can be easily computed.

Apart from molecular refractions, two other sources of estimating exaltations have appeared: (a) If b is the projection of the distance between the 4 and 4' positions onto an axis defined by the mid-points of the bonds in the polyene chain, and b_1^* is calculated for the "isolated" bonds alone, then

$$b_{\max} = b_1^* + kl^3$$

where k has a mean value of 1.13×10^{-2} ; l for the αw -diphenylpolyenes is $6.25 + 2.47n$ Å units. (b) If $\lambda_{\max} m\mu$ is the wave-length of maximum absorption for the K -band in a conjugated hydrocarbon, then $\Delta b_{\max} = b_{\max} - b_1^* = 9.762 \times 10^{-7} (\lambda_{\max} - 206)^3$.

As an illustration, the effect of using the second equation may be shown:

n	$10^{12} mK$ calc. (without exaltation)	$10^{12} mK$ calc. (with exaltation)	$10^{12} mK$ (observed)
1	45	111	124
2	62	358	357
3	82	764	692
4	105	1759	1740

"Corrections" by the other two routes mentioned are similar in magnitude. In general it appears that the "longitudinal" polarisability of a conjugated system is a function of the cube of its length—a prediction earlier made by Davies in 1952 from theoretical considerations.

More work is clearly needed on this important aspect of molecular polarisability. Before leaving for London last year Mr. Bramley had examined a number of conjugated ketones; his experiments are being continued and extended by Messrs. D. Izsak and M. Aroney. Discussion of them now would be premature, although it should be said that nothing to date has emerged which is in essential disharmony with the conclusions reached with the diphenylpolyenes.

Polarisabilities and Bond Lengths

Turning aside from the stereo-structural employments of polarisability, a few other aspects of interest have emerged during our work and justify a brief mention. Since by elementary electrostatics a conducting sphere of radius r placed in an electric field of intensity F acquires an electric moment of $r^3 F$ (i.e. its polarisability is r^3), it was natural to search among our bond data for relationships involving (bond-length)³.

Le Fèvre in 1958, considering the information which by then had accumulated on the principal polarisabilities of *single* bonds, observed that the *longitudinal* polarisabilities, b_L^{X-Y} , of such bonds tended to follow relationships of the type

$$10^{24} b_L^{X-Y} = A + Bd^3$$

in which A and B were constants, and d (in Ångström units) was obtained as follows: (a) when neither X nor Y is a terminal atom, $d = r_{X-Y}$ (the inter-centre distance), or (b) when Y is a terminal atom, $d = r_{xy} + r_Y$, or (c) when $X-Y$ is a diatomic molecule, $d = r_{XY} + r_X + r_Y$ (r_X and r_Y being the radii of atoms X and Y). Two equations were proposed:

$$10^{24} b_L^{X-Y} = 0.140 + 0.156d^3 \quad \dots\dots (i)$$

$$10^{24} b_L^{X-Y} = 0.106 + 0.186d^3 \quad \dots\dots (ii)$$

respectively to cover the b_L 's derived from the methyl halides and those from the cyclohexyl halides.

Table 2 shows forecasts made by (i) and (ii).

It is seen that predictions are fairly satisfactory. No analogous general expressions for the *transverse* polarisabilities b_T^{X-Y} have been found, but since for *single* bonds $b_{\text{mean}}^{X-Y} = (b_L^{X-Y} + 2b_T^{X-Y})/3$, estimates of b_T^{X-Y} are obviously accessible from bond refractivity data in conjunction with b_L^{X-Y} (calculated).

TABLE 2
Calculations of $10^{24}b_L^{XY}$

Bond	r_{XY} (Å)	r_Y (Å)	b_L by (i)	b_L by (ii)	b_L Found
N-H	1.01	0.30	0.5	0.5	0.5
C-H	1.09	0.30	0.6	0.6	0.6
C-N	1.47	—	0.6	0.7	0.6
C-O	1.43	—	0.6	0.6 ₅	0.8
C-C	1.57	—	0.7	0.8	1.0
C-F	1.38	0.64	1.4	1.6	1.2 ₅
C-Cl	1.78	0.99	3.4 ₅	4.1	3.2 (3.8 ^a)
C-Br	1.94	1.14	4.7	5.5	4.6 ₅ (5.3 ^a)
C-I	2.13	1.33	6.6	7.8	6.8 (8.1 ^a)
H-Cl ^b	1.27 ₅	0.99	2.8	3.2	3.1
H-Br ^b	1.414	1.14	3.8	4.4	4.2
H-I ^b	1.604	11.33	5.4	6.4	6.6

^a b_L^{XY} found in cyclohexyl halides.
^b r_X taken as 0.30 Å.

Experimental evidence on bonds of order higher than unity is scarce. It is relevant, however, that modifications of the above equations show promise. If, for example, (i) is written as (iii)

$$10^{24}b_L^{XY} = 0.140 + 0.156[d^3 + 9.5(r_{\text{single}}^3 - r_{\text{obsd.}}^3)]$$

.....(iii)

then the following forecasts are possible with $d=r_{\text{obsd.}}$.

Bond	$r_{\text{obsd.}}$	$10^{24}b_L$ calc.	$10^{24}b_L$ found
C=C	1.33	2.7 ₅ 2.8 ₀
C≡C	1.20	3.6 3.5
C=O	1.22	2.1 2.3
CO (Carbon monoxide)	1.14	2.5 2.6
CC (Aromatic)	1.40	2.2 ?

Equations of type (iii) moreover may be applicable to “single” bonds shortened by mesomerism, as in the tri- and tetrachloroethylenes, where the C-Cl separations are *ca.* 1.71 Å, or in the dichloroethylenes and chlorobenzene, where they are *ca.* 1.69 Å. If, with these r_{XY} ’s, d is calculated as for single bonds and inserted in (iii), longitudinal polarisabilities for C-Cl emerge which exceed by 0.7 or 0.8×10^{-24} , respectively, the value appropriate for a single bond attached to a methyl-group.

Thus, empirically at least, we find that longitudinal polarisabilities of bonds and the exaltations of polarisability of molecules can be connected with cubes of lengths.

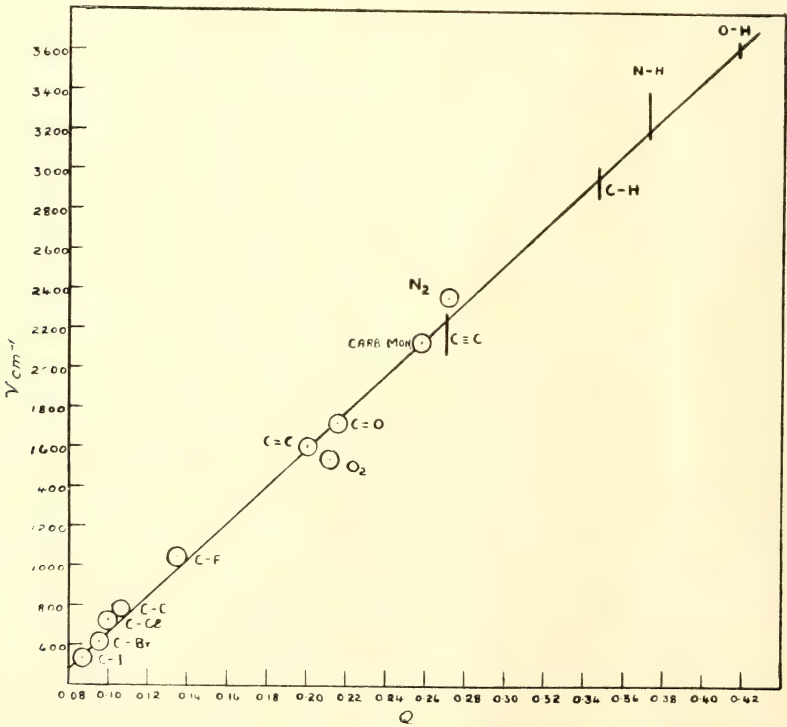


Fig. 1

Polarisabilities and Bond Stretching Frequencies

Another generalization deducible from Table 1 concerns a quantity Q given by

$$Q = (1/r_{XY}^2)(b_L^{XY}/\bar{M})^{\frac{1}{2}}$$

in which r is the internuclear distance in the link $X-Y$, \bar{M} is the reduced mass for $X-Y$, and b_L^{XY} is in units of 10^{-23} c.c. Straight-line relationships seem to exist between stretching frequencies ν (as cm^{-1}) and Q (see Fig. 1).

Le Fèvre (1959), noting that both ν and b_L^{XY} can vary somewhat with molecular environment so that many fairly similar equations can be written dependently on data sources chosen, suggested the following:

$$\nu = 9273 Q - 254.$$

From our viewpoint this is of value since by it the b_L^{XY} 's become predictable of bonds inaccessible to ordinary measurement *via* the Kerr effect. As illustrations, examples of cases where b_L^{XY} is already known and of others where it has yet to be determined are given in Table 3.

TABLE 3

Bond	ν (cm^{-1})	r (\AA)	b_L^{XY} (calc.)	b_L^{XY} (<i>ex</i> Kerr effect)
O—H	3650–3590	0.97	0.06	?
N—H	3400–3200	1.01	0.06–0.05	0.05
C—O	<i>ca.</i> 1100	1.43	0.18	0.08
C=O	1720	1.22	0.22	0.23
C=N	1690–1640	1.28	0.26–0.24	?
C≡N	2260–2240	1.15	0.30–0.29	?
C—C	802	1.54	0.12	0.10
C=C	1620	1.34	0.29	0.28
N=N	1630–1575	1.24	0.21–0.19 ₅	?
N≡N	2360	1.09	0.26	0.24
C—F	1048	1.39	0.14	0.12 ₅
C—Cl	732	1.78	0.34	0.32
C—Br	611	1.94	0.45	0.46 ₅
C—I	533	2.13	0.63	0.68
N—O	814–751*	1.37	0.07 ₅ –0.06	?
N=O	1681–1613*	1.22	0.22–0.20	?
N=O	<i>ca</i> 1400†	1.22	<i>ca</i> 0.14	?

* In alkyl nitrites.

† In nitrosamines.

As comment on these it can be said that a b_L^{O-H} of 0.06×10^{-23} is not excluded by the measurements of n -alcohols by Le Fèvre, Le Fèvre, Purnachandra Rao, and Williams (1960). The value 0.18×10^{-23} forecast for the C—O bond is quite incorrect; a value for b_L^{C-O} of 0.081 requires ν to be *ca.* 780 cm^{-1} which is much below assignments usually made by

infra-red spectroscopists. Malherbe and Bernstein (1952) attribute several frequencies observed in the Raman spectrum of dioxan to ring stretching, and among these is one at 834 cm^{-1} , annotated as polarised and strong; this being used b_L^{C-O} emerges as 0.09 . Frequencies near 750 cm^{-1} are recorded for many polymethylene chains, but are commonly ascribed to a rocking mode of the methylene groups; however, Ramsay and Sutherland (1947) consider 802 cm^{-1} to be "probably the symmetrical C—C stretching frequency" in cyclohexane, the compound from which Le Fèvre and Le Fèvre (1955) originally estimated b_L^{C-C} .

It is interesting to examine the reverse use of the equation, whereby a ν_{XY} is estimated from the b_L^{XY} given by the Kerr effect. Table 4 shows this:

TABLE 4

Bond	b_L^{XY}	ν (cm^{-1}), calc.	ν (cm^{-1}), obs.
C—H	0.064	2950	2962–2853
C=C	0.28	1605	1616 in CH_2 : CCl_2 ^a
C≡C	0.35	2240	2260–2100
C=O	0.23	1750	1718 in Me_2CO ^b
C—F	0.12 ₅	1000	1048 in MeF
C—Cl	0.32	710	732 in MeCl
C—Br	0.46 ₅	620	611 in MeBr
C—I	0.68	556	533 in MeI

^a Corresponding Raman displacement at 1611 cm^{-1} .

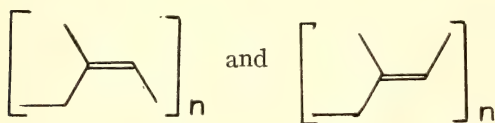
^b 1742 cm^{-1} in vapour.

Agreement appears satisfactory. Carbon monoxide, an isolated bond so to speak, with $r=1.14 \text{ \AA}$ and $b_L=0.26$, fits the equation precisely, ν (calc.) and ν (obs.) being 2143 cm^{-1} .

Polarisabilities and other Physical Properties

A knowledge of the anisotropy of molecular polarisability can sometimes provide information on the disposition of a given molecule in its crystal lattice. In combination with the measured density of the solid phase, b_1 , b_2 , and b_3 yield three "molecular refractions", R_1 , R_2 , and R_3 , from which three corresponding refractive indexes can be extracted. If one of these equals one of those observed for the crystal, the "lie" of one of the molecular axes is determined. Examples of this type of use are seen in Le Fèvre and Le Fèvre's (1955) treatment of naphthalene, or that by Bunn and Daubeney (1954) of hexatriacontane.

A number of other physical measurements in which either molecular or bond polarisabilities appear to be important are also receiving attention; two will be mentioned but cannot now be enlarged upon. The first concerns molar Verdet constants. In their 1955 Review the Le Fèvre's mentioned that these, for many molecules, seem to be linearly related to the sums of the products of the various principal molecular polarisabilities, *viz.* $b_1b_2+b_2b_3+b_3b_1$. The second concerns stress birefringence, especially in polymers. If a macromolecule is made up of mers, each with polarisabilities b_x , b_y , and b_z , in random array, then the birefringence Δn induced by a stress on the material in bulk is given by the "stress optical coefficient" $C=2\pi(n^2+2)^2(b_x-b_y)/45nkT$, where n is the ordinary refractive index. As stated above, both rubber and gutta-percha are being studied by us; these are poly-*cis*- and poly-*trans*-isoprenes respectively, and the constituent mers are



From our C-C, and C=C bond data, b_x-b_y is *ca.* 0.25×10^{-23} for both. With $n=1.52$ the calculated stress optical coefficient emerges at $2.1-2.2 \times 10^{-10} \text{ cm}^2/\text{dyne}$, which agrees with the value listed by Stein (1956) for Hevea Rubber at 30° . We are hoping that similarly satisfactory calculations will apply to other polymers now engaging Dr. Sundaram.

Possible Future Developments

By Liversidge's Will the lecturer is charged also with "drawing attention to the research work which should be undertaken . . .". Where the wider aspects of my subject are concerned, perhaps this can most neatly be done by saying that nine ways may be foreseen whereby the imposition of electric or magnetic fields may cause anisotropy of a liquid or gas composed of anisotropic molecules, whose random orientations are partially destroyed by orientations caused by the applied field. In theory, effects should be observable on the dielectric constant ϵ , the magnetic permeability μ^* , and the refractive index n :

Field Applied	n	ϵ	μ^*
Electric	Δn	$\Delta \epsilon$?
Magnetic	Δn	?	?
Optical	?	?	?

Of the six possible phenomena associated with electric and magnetic fields, three have been discovered by experiment, and only one of these—the Kerr effect—can be said to have been extensively investigated from a molecular structural viewpoint. Even so, much straightforward work remains to be done, e.g., the dependence of the Kerr effect on state—a matter taken up so far only in two papers, and which really requires a long series of patient measurements on gaseous dielectrics.

We in Sydney are beginning a study of "magnetic birefringence"—the "Cotton-Mouton effect" (in which the molecular anisotropies of both optical polarisability and magnetic susceptibility are concerned); our plans are to proceed along lines parallel to those used with the Kerr effect. The other "effects"—less interpretable and more difficult to detect—we leave to resourceful posterity!

The idea that a very intense beam of polarised light ("optical fields") may cause anisotropy of observable properties is due to Dr. A. D. Buckingham, an old student and one-time collaborator of ours. His theory is set out in papers in 1956 and 1957. Luminous fluxes of a very high order will be required if his "effects" are to be amenable to laboratory study; perhaps the techniques of flash photolysis will help . . . anyway, here is a discovery half made!

Acknowledgements

I desire to record my deep gratitude to all my co-workers and students, past and present, who have contributed magnificently by their labours, and taught me so much by their discussions. Their names have been mentioned above and occur again in the references listed below. Especially do I acknowledge my debt to my wife, Dr. Catherine Le Fèvre, my equal collaborator for nearly 30 years, without whose persistent struggles with the principles and techniques of physical optics, never-ending patient experimentation, and help in innumerable ways, this work could never have been done in the University of Sydney.

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Notes on Some Additional Minerals from the Oxidized Portion of the Broken Hill Lode, N.S.W., with Observations on Crystals of Coronadite

L. J. LAWRENCE

(Received June 23, 1960)

ABSTRACT—Six additional secondary minerals: chalcophanite, hydrozincite, aurichalcite, olivenite, acanthite and goslarite are recorded from the Broken Hill lode N.S.W., and some crystallographic data on single crystals of coronadite is presented.

Introduction

Recent mining operations by Broken Hill South Limited in and adjacent to the Open Cut has revealed the presence of a number of additional minerals not recorded in the previous accounts of the mineralogy of the Broken Hill lode (Smith, 1926; Stillwell, 1953). These minerals are all of a secondary nature and have formed late in the oxidation cycle insofar as they occur as overgrowths on earlier formed secondary minerals.

The identity of each mineral has been verified by X-ray diffraction measurements and, where appropriate, by optical properties either in transmitted or in reflected light.

1. Chalcophanite, $(\text{ZnMnFe})\text{Mn}_2\text{O}_5 \cdot 2\text{H}_2\text{O}^*$

Numerous specimens of crystallized chalcophanite were found lining small cavities in and forming a velvet-like overgrowth upon stalagmitic pyrolusite. The minute crystals range in size from 0.02 mm to 0.05 mm diameter and consist of very thin hexagonal plates of a lustrous deep purple-red colour.

In polished section (Plates 1 and 2) those crystals the "c" crystallographic direction of which is approximately parallel to the plane of the section, show maximum reflectivity of a strong white colour and have very strong reflection pleochroism from white to dark grey with sharp parallel extinction. These sections possess extreme anisotropism of a uniform white colour. Basal sections are not so strongly reflecting and their isotropism is always masked by a most intense carmine red internal reflection when viewed between crossed polars. Internal

reflections are also observed in ordinary light but the intensity is considerably subdued. Twinning is evident in basal section (Plate 2) where the optical continuity, as evidenced by uniform reflection and the co-planar arrangement of the extensive 0001 faces suggests that the twinning occurs on the 1120 (prism) plane.

The host material consists of a rhythmically banded psilomelane of a distinctly blue-grey colour in reflected light, together with pyrolusite of a creamy white colour in perfect colloform arrangement (Plate 1). The outer layers give way to a confused aggregate of minute pyrolusite crystals with the chalcophanite crystals lining the outermost surface. In a few instances the chalcophanite supports isolated nests of hair-like coronadite crystals (*q.v.*). Chalcophanite occurs also investing and, in part, replacing embolite.

2. Hydrozincite, $\text{Zn}_5(\text{OH})_6(\text{CO}_3)_2$

Among the many pieces of smithsonite obtained from a large mass of coronadite ore at the base of the Open Cut were several, both of the globular and of the dog tooth type, which appeared to have been converted to a white porcellanous mineral. The white mineral proved to be hydrozincite.

The dog tooth crystals were, in most instances, complete pseudomorphs of hydrozincite after smithsonite but the globular masses were, in general, only partially replaced (Plate 3), leaving remnants of unreplaced smithsonite.

The hydrozincite is of the harder compact type and is barely translucent in thin section. The mineral is cryptocrystalline (colloidal) except for the profuse development of hysteresis fractures resulting from the hardening of the hydrozincite colloid.

* The chemical formulae cited herein are those given in Dana's System of Mineralogy, vols. I and II (new editions).

3. Aurichalcite, $2(\text{ZnCu})\text{CO}_3 \cdot 3(\text{ZnCu})(\text{OH})_2$

The 350' level of the South Mine yielded several pieces of cuprite liberally coated with malachite and externally covered with fine acicular crystals of a pale sky blue colour.

The following optical properties were determined on some detached crystals: $X=a$ with $n=1.65$; $Z=c$ with $n=1.75$; straight extinction; pleochroic in thicker pieces from colourless to faint blue-green. These determinations together with "d" and "I" values confirm the identity of the mineral as aurichalcite. This mineral, the occurrence of which at Broken Hill was alluded to by Smith (*loc. cit.*) but never confirmed, is much paler in colour than the classic material from Kelly, New Mexico, but the X-ray diffraction patterns of the two are identical.

4. Olivenite, $\text{Cu}_2(\text{AsO}_4)(\text{OH})$

Two pieces of lode material encrusted with a fine granular apple green mineral were obtained from the southern end of the Open Cut. The green mineral has been identified as olivenite which, under high magnification, is seen to be minutely crystallized.

Olivenite has been recorded only twice previously in Australia: at Kundip in Western Australia and at Mount Diamond near Pine Creek in the Northern Territory. The very limited occurrence at Broken Hill of this rare copper arsenate is due, no doubt, to the scarcity of primary arsenic minerals.

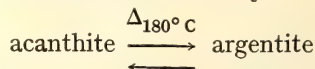
5. Acanthite, Ag_2S

The orthorhombic form of silver sulphide was found in the 350' level of the South Mine. One large mass weighing some 70 lb. and several smaller pieces were obtained. The mineral is soft and sectile, of a dull grey colour with a shining metallic streak and contained numerous small grains of extraneous material such as garnet, quartz, plentiful iron oxides and cerussite. It is clearly of a supergene nature and was closely associated in the stope with iodyrite and embolite.

A differential thermal analysis of the silver sulphide after acid leaching to remove iron oxides (Fig. 1) shows a sharp endothermic peak at 180°C representing the inversion from the orthorhombic form (acanthite) to the unstable isometric form (argentite). The progressive breakdown of the silver sulphide with loss of sulphur is spread over a range of temperatures reaching a maximum at 700°C . The D.T.A. run was repeated several times without removing

the specimen from the oven. In each case the heating curve and the cooling curve were identical and the inversion point constant.

This spontaneous reversibility:



agrees with the earlier findings of Ramdohr (1942) and the much later work of Roy *et al.* (1959).

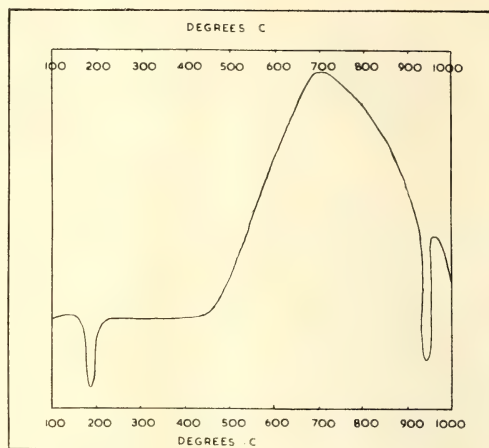


FIG. 1

Differential thermal analysis curve of Broken Hill acanthite (corrected for base line drift) showing acanthite-argentite inversion point at 180°C , the progressive exothermic rise to a 700°C peak due to loss of sulphur and the ultimate melting of the resulting metallic silver indicated by a sharp endothermic peak at ca. 960°C

Chemical analysis of the Broken Hill acanthite gave the following results:

Ag	..	..	..	62.2
Cu	..	..	..	2.1
S	..	..	..	9.0

Remainder, mainly iron oxides (26.7).

These figures indicate an Ag:Cu percent ratio of 84.8:2.8. The mineral contains insufficient copper to rank as the cuprian variety jalpaite $(\text{Ag,Cu})_2\text{S}$ which has been recorded from Broken Hill by Stillwell (*loc. cit.*) as supergene replacements of primary galena.

6. Goslarite, $(\text{ZnSO}_4 \cdot 7\text{H}_2\text{O})$

The only recorded sulphates from the oxidized zone at Broken Hill are the insoluble salts anglesite, linarite and brochantite. The common soluble sulphates chalcantite and melanterite have not been noted, and, with the abundance

of zinc minerals, it is perhaps not surprising that the rarer zinc sulphate, goslarite, occurs preferentially, though not hitherto recorded.

Several fine specimens of goslarite of a delicate coral pink colour (due to the admixture of manganese) were found in the shallow levels of the South Mine immediately beneath the Open Cut. The goslarite consists notably of stout stalactites up to four inches long adhering to quartzose lode material and as microcrystalline masses lining cavities and joints in low grade ore. The interior of some of the stalactites is more or less hollow and the inner surfaces are sometimes lined with well-formed crystals of the same mineral, up to $\frac{1}{8}$ " in length.

A partial chemical analysis showed a ZnO to MnO ratio of 33.2:4.1 and this may be sufficient to identify the Broken Hill material as a "mangangoslarite".

Coronadite Crystals

The occurrence at Broken Hill of coronadite ($\text{MnPbMn}_6\text{O}_{14}$; ? pseudo-tetragonal) as colloform masses, rarely with a radiating fibrous texture, is well known; it is now possible to record, for the first time from this locality, single crystals of this rare mineral. The crystals are very minute—rarely exceeding 0.1 mm in length—but are well formed and of an extremely acicular habit. The X-ray data obtained by means of a Phillips 1010 diffractometer ($\text{CuK}\alpha$, 1.54R) agreed precisely with that of Frondel and Heinrich (1942) on material from Clifton-Morenci, Arizona with the exception of a strong peak at "d" 3.02. This line is not listed by Frondel and Heinrich and may be due to impurity.

The coronadite crystals occur either in small cavities in psilomelane where they are supported by crystals of chalcophanite, or as an outer coating of clustered crystals of random orientation upon stalagmitic limonite and psilomelane. When thus aggregated the coronadite is of a distinct indigo-grey colour.

The crystals are sufficiently lustrous to examine in reflected light by immersion in cedar oil. They show strong reflectivity of a white colour and have sharp straight extinction. Between crossed polars the crystals exhibit strong anisotropism of white, dark grey and dark brown. An unusual prismatic cleavage is evident in many crystals (Plate 4) and this gives rise to a pronounced fraying at the terminal ends of the crystals and often spreads almost the full length of the crystal.

The crystals appear to consist predominantly of prism (110) and basal pinacoid (001) but there is evidence of the development of two or three pyramidal faces. One of these faces, measured in profile under the microscope, indicated an interfacial angle of approximately 55° with respect to the prism and another approximately 45° . Twinning is a feature of some crystals with a steep pyramidal face as the twin plane. This results in the development of well-formed arrow-head twins (inset of Plate 4) having an included angle of 56° ; this would indicate an internal angle of 28° between this particular pyramid and the prism.

Acknowledgements

The attention of the author to some of the minerals described in this paper was drawn by Mr. Albert Chapman of Glebe, Sydney, who, in association with Mr. Arthur Campbell of Broken Hill—both leading collectors of Broken Hill minerals—has contributed much to the mineralogy of this locality. The enthusiasm with which these gentlemen preserve "new finds" for detailed study is well worthy of recording. In this regard, also, the author offers his thanks to the Staff of Broken Hill South Ltd. for their vigilance in preserving unidentified minerals found in that mine. Mr. R. Coote of the Department of Fuel of the University of New South Wales produced the excellent photomicrographs and Mr. G. T. See carried out the chemical analyses.

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Explanation of Plates**PLATE 1**

Tabular crystals of chalcophanite resting within a nest of crystals of the same mineral cut approximately parallel to their "c" crystallographic axes. The dark grey mottled mineral at the top is embolite. The base of the specimen consists of limonite (dark grey), psilomelane (whitish) and pyrolusite (light grey mottled) all in perfect colloform arrangement. (Oil immersion, reflected light $\times 1000$.)

PLATE 2

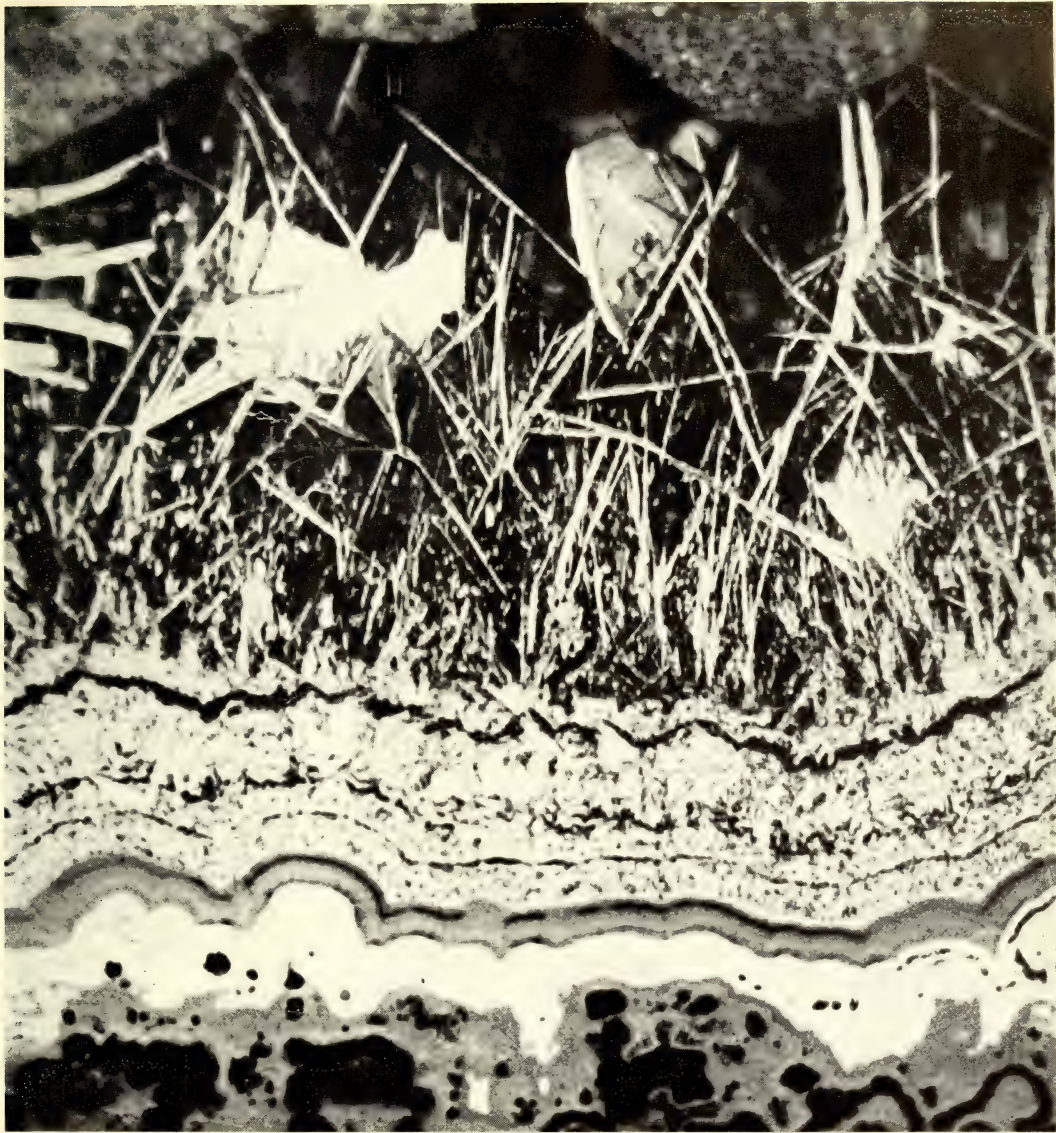
Chalcophanite crystals lining a small cavity in pyrolusite-limonite and embedded in clear plastic. The two highly reflecting crystals are orientated approximately normal to the "c" crystallographic axes and the one on the left-hand side shows twinning apparently on the (1120) plane. (Oil immersion, reflected light $\times 1000$.)

PLATE 3

Hydrozincite (dark—almost opaque area) showing profuse development of anastomosing hysteresis fractures, replacing smithsonite with a remnant of unreplaced zinc carbonate top right. (Transmitted light. $\times 20$.)

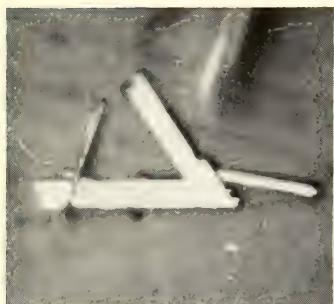
PLATE 4

Single crystals of coronadite. Some of the smaller crystals, e.g. at X, show a fraying due to pronounced prismatic cleavage. Inset shows a characteristic arrow-head twin. (Oil immersion reflected light. $\times 750$.)









The Lambie Group at Mount Lambie Part I: Stratigraphy and Structure

ROBIN M. MACKAY

(Received August 9, 1960)

ABSTRACT—At Mt. Lambie, the Lambie Group consists of some 10,000 feet of sandstone, siltstone and shale with subordinate conglomerate. The structure and petrology of the sediments are described in some detail.

Introduction

The sediments outcropping around Mt. Lambie (Fig. 1) have been the subject of numerous geological examinations. A résumé of the literature dealing with this area was given by Brown and Joplin in 1938. Since that time relevant literature has been limited to a brief mention of the thickness of the sediments at Mt. Lambie by David (1950), McElroy (1957) and Branagan (1958), and to Maxwell's (1950 and 1951) description of some *Cyrtospirifers* from this group.

Thickness and Succession

The Lambie Group outcrops extensively south and east of Mt. Lambie. To the south it is invaded by the Bathurst granite and in the north it is overlain unconformably by the

almost horizontal, basal conglomerates of the Permian Capertee Group (David, 1950, vol. 1, p. 248). It unconformably overlies rocks of uncertain age henceforth referred to as ? Middle Palaeozoic. These older rocks consist of a succession of about 5,000 ft. of shales overlain conformably by a conglomerate horizon containing limestone pebbles, and then by several thousand feet of tuffs, greywackes (Pettijohn, 1957, p. 291) and acid volcanics.

The evidence for the unconformity is entirely structural and relies heavily on the observed attitude of the ? Middle Palaeozoic conglomerate horizon (Fig. 2). Unfortunately this horizon thins and eventually pinches out before the boundary of the Mt. Lambie Formation is reached. However, the strike and dip of this horizon is markedly divergent from the dominant east-west strike of the Mt. Lambie Formation

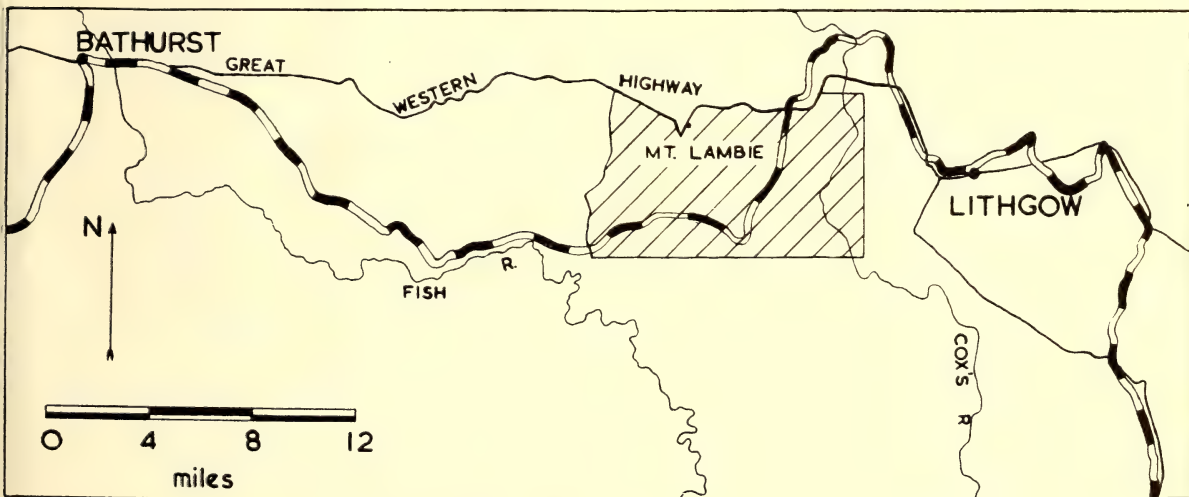


FIG. 1

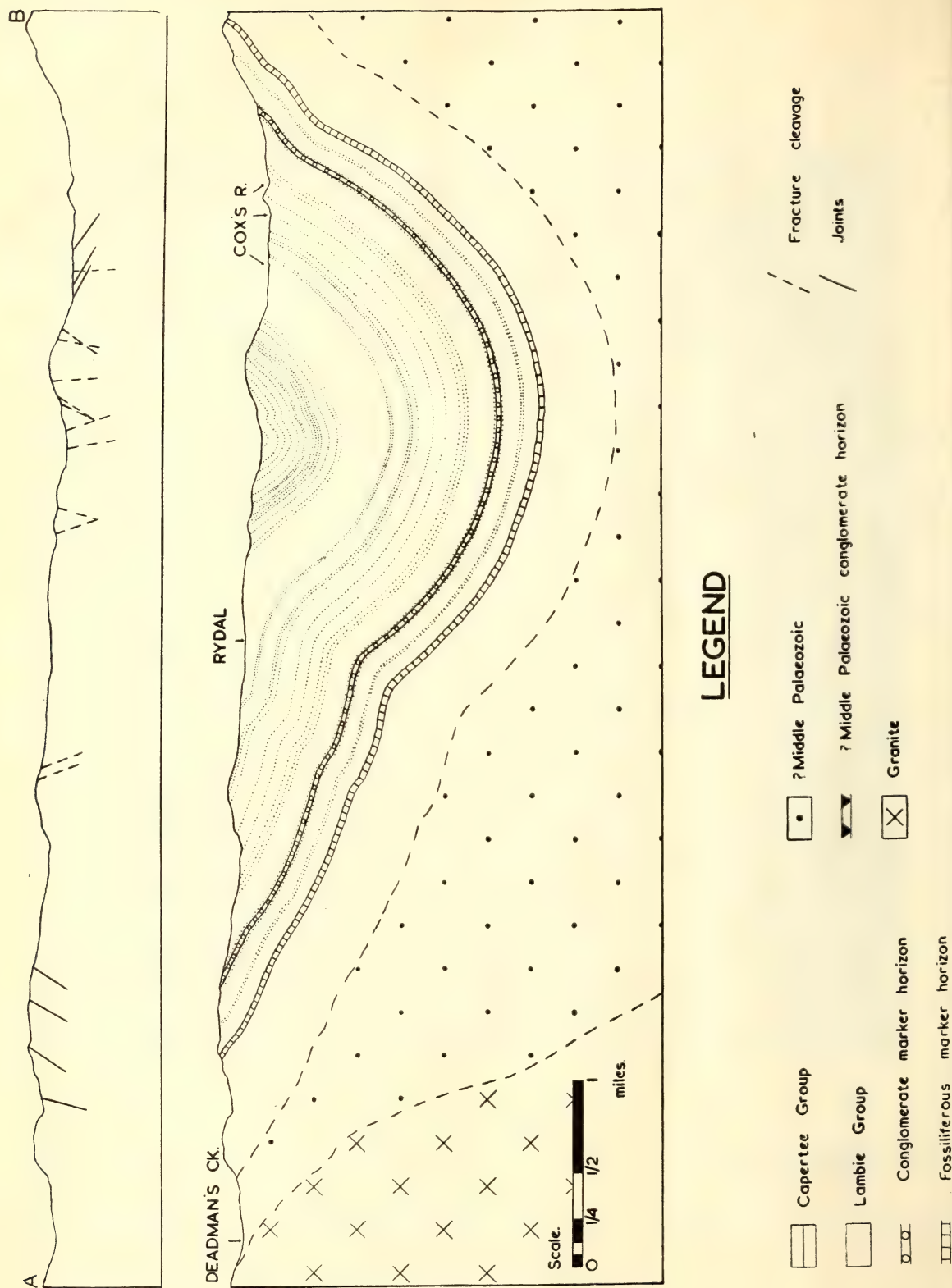
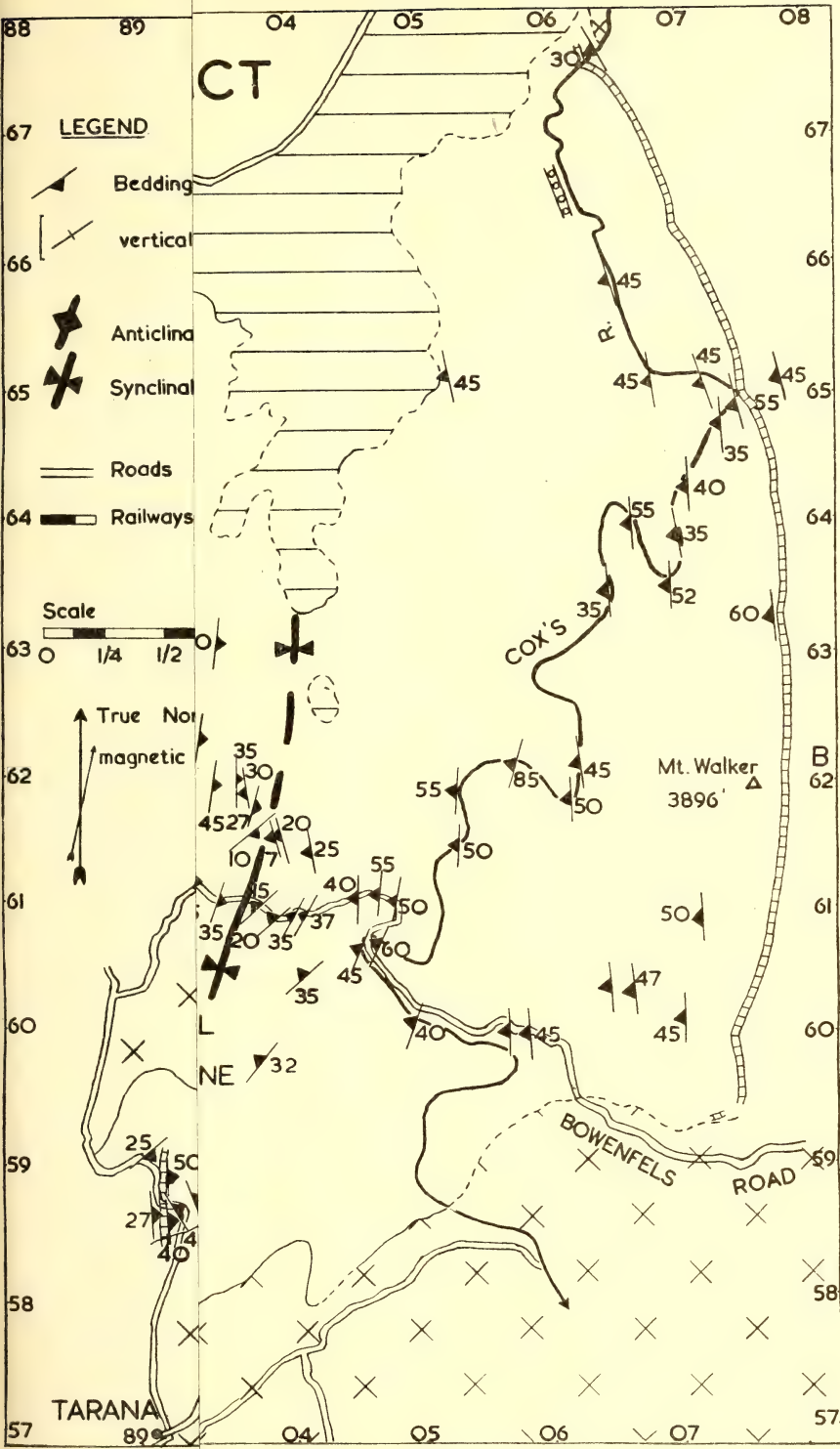
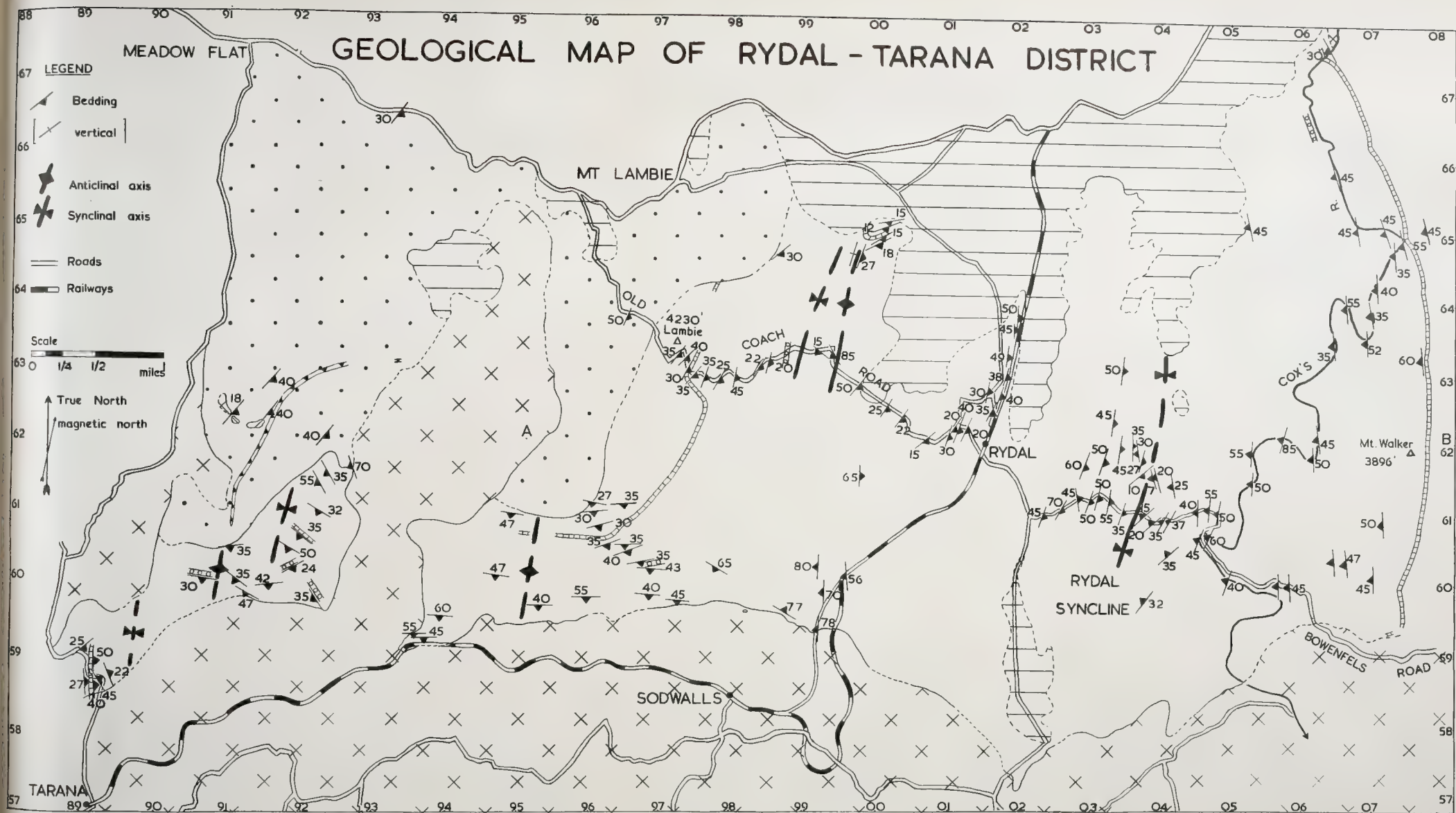


FIG. 3





immediately to the south, where also the base of the Mt. Lambie Formation is seen to overlap from the acid volcanics onto the stratigraphically lower shales.

Estimates of the thickness of sediments of the Lambie Group have varied considerably. Wilkinson's (1875) original 10,000 ft. of sediments was reduced by Brown and Joplin (1938) to 2,500 ft. "above the *Spirifer* bed", whilst recent estimates are "possibly more than 5,000 ft." by David (1950), 5,000 ft. by McElroy (1957) and 6,500 ft. by Branagan (1958).

The type section for the Lambie Group chosen by the present writer is located along the old Mt. Lambie Coach Road and the Bowenfels Road. This measured traverse, combined with some sixty bedding readings obtained along the road and in the nearby creeks, yielded the following succession.

	Erosion surface
180'	Red siltstone
270'	Green and purple shale
170'	Purple shale
160'	Green and purple shale
220'	Grey and reddish siltstone
170'	Purple shale
50'	Grey siltstone
220'	Purple shale
70'	Grey siltstone
80'	Purple shale
70'	Grey siltstone
220'	Red and purple shale
270'	Grey siltstone
140'	Purple shale
1320'	Purple and buff shale
50'	Black shale
600'	Buff siltstone
60'	Buff and grey siltstone
160'	Buff and red shale
440'	White and pale brown fine sandstone
330'	Buff and purple shale
550'	Buff siltstone
50'	White fine sandstone
830'	Purple shale
40'	Purple and grey siltstone
60'	CONGLOMERATE
40'	Purple shale and siltstone
500'	White and pale brown sandstone
50'	Purple siltstone
550'	White sandstone
20'	FOSSILIFEROUS WHITE SANDSTONE
2200'	White and pale brown sandstone
	Basal Unconformity

Total : 10,200'

For the compiling of the section (Fig. 3) this information was projected onto an east-west vertical plane passing through Rydal. The section thus obtained is situated a little to the south of Wilkinson's original section but coincides exactly in position with that of Brown and Joplin (1938). The extension of the section in depth is of necessity hypothetical. Moreover,

the presence of recrystallized rocks in the vicinity where the section line crosses Cox's River indicates that, there at least, granite is present at only a short distance beneath the surface. The basis for the overall concentric style of folding shown in the section will be discussed in the following structural section.

In general, the individual beds have not been mapped on the eastern limb of the syncline, as they are somewhat metamorphosed and difficult to correlate with corresponding beds outcropping in the west. However, the lowermost 2,200 ft. of white and pale brown sandstone are readily located on the eastern limb of the syncline as are also the fossiliferous and conglomerate marker horizons.

Sedimentary structures are limited to cross-bedding in units 2 in. to 5 in. wide in the siltstones and occasional units up to 2 ft. wide in the sandstones. Ripple marked bedding planes are not uncommon in the sandstones.

The variety of sediments in the succession at Mt. Lambie would enable the Group to be divided into at least two formations each containing several members. Probably the most logical place to draw the boundary between the two probable formations is at the base of the conglomerate horizon. The mapping required to place the boundary of the formations on the map has not yet been carried out. Work in the area is, however, in progress as part of a regional study of a more extensive area centring around Mt. Lambie.

Structure

In delineating the structure of the Lambie Group two marker horizons, the fossiliferous sandstone horizon and the conglomerate horizon, were found very useful. It should be noted here that Brown and Joplin were incorrect in their mapping of the outcrop of the fossiliferous sandstone horizon as comparison between their Fig. 1 and Fig. 2 of the present paper readily shows. This error is largely responsible for their obtaining such a small thickness for the sedimentary succession.

With regard to the conglomerate marker it should be noted that some degree of facies change was observed in this horizon. In the east and centre of the area it has essentially a purple siltstone matrix, whilst in the west the matrix is coarser and more quartz rich.

The overall structures developed in the Lambie Group are open concentric folds although a sharp flexure in the vicinity of g.r. (995640)*

* Grid references refer to the Wallerawang and Bathurst 1:63,360 military maps, and may be read directly from Fig. 2.

shows that locally minor structures may be much tighter. The fold axes strike approximately N. 15° E. and plunge 10° S. The axis of the Rydal syncline does however curve around to due north and probably to N. 20° W. underneath the Capertee Group in the north-eastern part of the area (see Fig. 2).

The major factor which controlled the deformation of the Lambie Group is the competency of the lowermost 3,000 ft. of sediments which consist mainly of quartz-rich sandstones. The sandstones are cut by prominent rotational joints (see Fig. 3) whose spacing generally varies from 2 ft. to 6 in., though exceptionally these joints may be as closely spaced as 2 or 3 in. Tensional joints across the nose of the central anticline striking approximately 285° and dipping vertically or steeply north, are sometimes observed.

The uppermost 3,500 ft. of shales and siltstones are deformed in a somewhat different manner from the lower sediments of the group. They are cut by a prominent fracture cleavage whose spacing varies from $\frac{1}{8}$ in. to $\frac{1}{2}$ in., but some of the more massive siltstones have a very closely spaced jointing transitional between the cleavage of the shales and the jointing of the sandstones. The fracture cleavage in the shales and siltstones is usually steeply inclined and somewhat irregular due, most probably, to crumpling of the shales as they were compressed into the shape prescribed by the folded competent sandstones. Despite these irregularities, there seems to be an overall tendency for the fracture cleavage to fan across the syncline, converging downwards.

Petrology

For the purposes of description the sediments of this group can be divided into two main groups; the sandstones, and the siltstones and shales. The sandstones show remarkably constant characteristics, their average grain size varying from 0.1 to 0.2 mm. Quartz comprises 80% to 95% of the detrital grains, the remainder consisting of small fragments of feldspar, metaquartzite, mudstone and less commonly mica-schist. A small percentage of detrital mica is also present, while detrital magnetite averages 1% to 2%. Zircon and tourmaline, typically well-rounded, are the only other heavy minerals present. The original detrital grains were fairly well-rounded but authigenic outgrowth of quartz tends to obscure this feature. Quartz is generally the only mineral cement present although calcite is

found in the sandstones associated with the fossiliferous horizon.

The characteristics described place the sandstones into Pettijohn's (1957, p. 291) proto-quartzite group and into Packham's (1954) quartzose sandstone group. Both these groups are thought by their authors to be typical of sedimentation in shallow water shelf areas.

The siltstones and shales, average grain size 0.05 to 0.1 mm., are, without exception, "dirtier" than the sandstones, their quartz content ranging from 40% to 70%. The remaining detrital material in the siltstones consists of grains of magnetite, fragments of feldspar, rock fragments and flakes of white mica and very rarely fresh biotite. Variation in the percentage of detrital magnetite, which may make up as much as 10% of the rock, is responsible for much of the banding of the siltstones. The green siltstones and shales owe their colour to the presence of approximately 15% of a green clay mineral, probably chlorite. Zircon and tourmaline are less common than in the sandstones, but are found in some samples. Authigenic outgrowth of quartz is again much in evidence, but the larger grains are seen to have been fairly well-rounded.

Apart from their quartz content, the shales consist of grains of magnetite, very fine micaceous material and small amounts of carbonate. The smaller quartz grains in the shales are quite angular as would be expected, since grains of such a small size are not readily rounded during transportation. Joplin (1935, p. 20) suggested that the red shales at Mt. Lambie were of tuffaceous origin, on the basis of the angularity of their quartz grains. There is, however, no evidence to support a pyroclastic origin for these shales.

Finally, the conglomerates consist of pebbles, average size 5 mm., but ranging up to several centimetres in diameter, set in a purple siltstone or a quartzose sandstone matrix. They consist of quartz (60%) and fragments of siltstone and occasionally metaquartzite. The variation in roundness of the pebbles is greater than that of the grains in the sandstones, but the larger pebbles generally show well-rounded outlines.

Acknowledgements

I would like to thank Professor C. E. Marshall, in whose department the work for this paper was carried out. I would also like to thank Dr. T. G. Vallance and Mr. B. Hobbs for helpful advice and criticism.

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The Geology and Petrology of the Uralla Area, N.S.W.

R. H. VERNON

(Received July 21, 1960)

ABSTRACT—In the Uralla area, N.S.W., Palaeozoic sediments (greywackes, greywacke-conglomerates and argillites), together with associated igneous dyke-rocks, have been subjected to thermal metamorphism by a granodiorite-adamellite intrusion. The intrusion grades from granodiorite at its margins to a central area of adamellite. This gradation is believed to have been caused by contamination with basic igneous rock, the effects of which were felt more in the marginal parts of the mass. Other igneous rocks occurring in the Uralla area include quartz porphyry, porphyritic microdiorite, teschenite, and olivine basalt.

Introduction

The town of Uralla lies about 13 miles south-west of Armidale, New South Wales. The Uralla area has been mapped by Voisey (1942) and his map, with certain alterations, has provided a basis for the present study (Fig. 1). The area shown on the map as "Uralla Beds" also includes numerous acid and intermediate dykes not mapped individually. A number of specimens collected from outside the area shown in Fig. 1 have also been examined.

The relationships between the major rock units are shown in Fig. 1. The central part of the Uralla area is occupied by a late Permian (?) mass composed of granodiorite and adamellite, which extends further to the north and south of the area shown in Fig. 1, forming a body of batholithic dimensions. This is part of the large acid-intermediate igneous complex extending from Stanthorpe in Queensland southwards to Tamworth, often referred to as the New England Batholith. The granodiorite-adamellite body is flanked by older Palaeozoic sediments (Uralla Beds) and dyke-rocks to the west and south-east (Fig. 1). A contact metamorphic aureole separates these rocks from the granodiorite-adamellite. In the highest parts of the area, namely in the north and north-east, Tertiary fluvio-lacustrine deposits belonging to the Armidale Beds occur capping the Palaeozoic rocks. Remnants of flows of olivine-basalt overlie these sediments or rest on the Palaeozoic rocks.

Physiography

The Uralla area is part of the New England Tableland, a partly dissected, uplifted peneplain. The Main Divide, which is an erosional feature separating the east- and west-flowing rivers in southern New England (cf. Voisey, 1957), runs approximately north-south along the

eastern edge of the Uralla area. It is marked by the elongated outcrop of acid porphyry in the south-east of the area, and follows the line of basalt to the north (Fig. 1). It is a line of low hills rising only a few hundred feet above the surrounding country. Between Uralla and Armidale it is about 3,500 feet above sea level (Voisey, 1957, p. 131).

The Main Divide and the country immediately to the east and west of it in the Armidale region constitute an erosion surface called the Laterite Surface (Voisey, 1957, p. 130). In the Uralla area its various characteristics are well shown. Swamps and lagoons are present (Fig. 1), the sparse hills are capped with basalt, and lateritic deposits (e.g., "ironstone gravel") occur locally. The surface is very flat, with an extensive soil cover, so that outcrops of the granodiorite-adamellite and the Uralla Beds are generally rather poor.

The western boundary of the Laterite Surface is shown in Fig. 1. The Post-Laterite Surface to the west is lower and more dissected than the Laterite Surface. It is drained particularly by Kentucky Creek and Rocky River, which flow northwards to join the west-flowing Bundarra River. The town of Uralla lies on this surface in the narrow valley of Rocky Creek. Rock exposures, especially of the granodiorite-adamellite, are generally better on the Post-Laterite Surface.

Uralla Beds

The term "Uralla Beds" is used for these rocks, since they cannot be correlated with any certainty with those rocks near Armidale considered by Spry (1953, p. 129) to be part of the "Woolomin Group". So far the Uralla Beds have yielded only a few poorly preserved plant remains found alongside the Uralla-Walcha road in the south-east of the area (Portion 117, Parish of Harnham). Lithologically similar

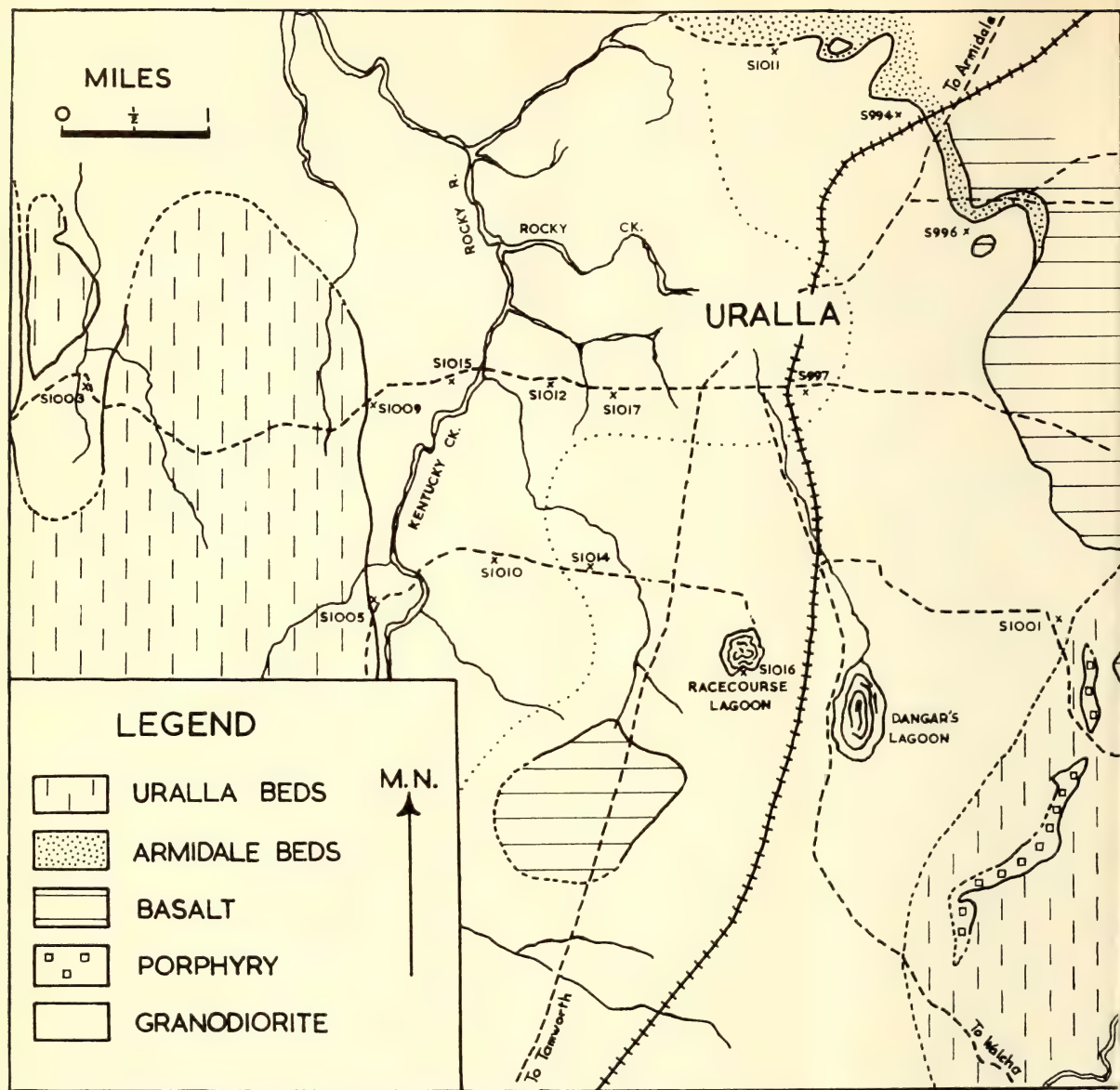


FIG. 1

Geological sketch-map of the Uralla area. The dotted line represents the approximate western boundary of the Laterite Surface after Voisey (1957)

rocks throughout New England are generally regarded as being of middle Palaeozoic age.

The beds strike generally north and dip $40-60^\circ$ W, with local sharp variations and occasional overturning. The most complete sections observed occur along Reedy Creek, about $3\frac{1}{2}$ miles to the north of the area shown in Fig. 1. Graded bedding indicates that the top of the sequence is to the west. The sediments consist chiefly of greywacke, which is interbedded with some greywacke-conglomerate

and silty argillite, the most common association being greywackes alternating with generally thinner beds of silty argillite. The beds of greywacke, which commonly are graded, invariably have sharp lower contacts and normally have sharp upper contacts, although some grade upwards into argillite. Angular chips of argillite are commonly incorporated in the base of greywacke beds. A little vitric tuff has been found interbedded with greywackes in the south-east of the area.

TABLE 1
Approximate Modes of Uralla Sediments

Rock type				Greywackes					Argillite
Specimen No.*	..	..	S980	S974	S976	S973	S977	S981	
Quartz . . . . .	..	..	8	7	3	9	4	3	
Chert .. . . .	..	..	7	5	4	2	15	2	
Plagioclase .. . . .	..	..	5	11	6	10	14	5	
Orthoclase .. . . .	..	..	—	1	—	—	—	—	
Rock fragments .. . . .	..	..	59	50	67	42	26	22	
Matrix .. . . .	..	..	21	25	19	35	38	68	
Cement .. . . .	..	..	—	1	1	2	3	—	

* Geology Department catalogue numbers, University of New England.

Petrography—Approximate modes of five Uralla greywackes and one silty argillite are given in Table 1. The greywackes plot as labile greywackes on the diagram of Packham (1954, p. 472). The argillite plots in the same field, but further towards the matrix vertex (Fig. 2). Because of their coarse grain-size, the greywacke-conglomerates are unsuitable for modal analysis. However, in view of their decreased matrix content, they would plot further towards the (feldspar+rock fragments) vertex.

The *greywackes* are dark grey with shades of green and blue in fresh hand specimens. As seen in thin section, they are poorly sorted

sediments consisting of angular fragments of quartz, feldspar and rock detritus, embedded in a prominent matrix (usually greater than 20 vol. per cent). Most detrital particles are of sand size, though a few larger fragments are commonly present. The largest fragments (up to 5×2 mm) are the black argillite "chips" of intraformational origin, mentioned above.

The mineral fragments are mainly of quartz and feldspar. The quartz has a roundness of 0.15–0.6 (Pettijohn, 1957, p. 59, Table 16), and a sphericity of 0.4–0.8 (Krumbein and Sloss, 1951, p. 81, Figs. 4–9). Some quartz grains are fractured and others are partly disintegrated, but most of the quartz does not

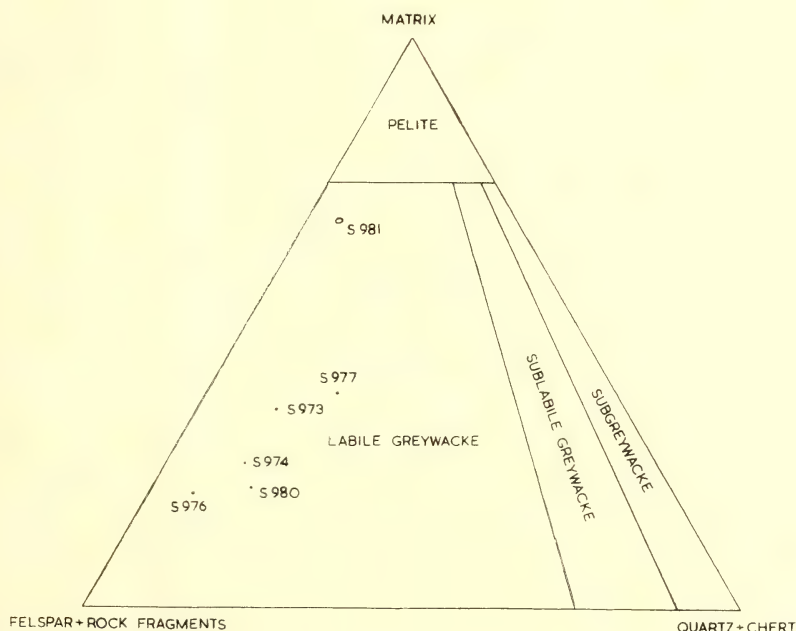


FIG. 2
Modal composition of some Uralla sediments plotted on the diagram of Packham (1954)

show undulose extinction. The inclusions in the quartz are globular, acicular and "dusty" and are irregularly distributed, these characteristics suggesting an igneous source for the quartz (Keller and Littlefield, 1950). Rounded, embayed quartz grains indicate that some of the quartz has been derived from acid volcanic rocks. The feldspar fragments, dominantly plagioclase, are generally more rounded than the quartz, and are kaolinized and sericitized to varying degrees. The plagioclase is commonly twinned and rarely zoned. Measurement of its refractive indices is made difficult by generally severe alteration, but indicates compositions varying from albite to oligoclase in different rocks. A little potash feldspar is also present. Allogenic ferromagnesian minerals are uncommon, minor amounts of amphibole and warped biotite being present locally in some of the greywackes. A little detrital muscovite, magnetite, apatite and zircon is commonly present.

The rock fragments are largely of igneous origin, volcanic and hypabyssal (intermediate and acid) types predominating. Smaller quantities of sedimentary fragments are also present. The rock types represented include rhyolite, spherulitic rhyolite, quartz-feldspar porphyry, andesite, trachyte, granophyre, basalt, chert, siltite, argillite, and a little jasper.

The matrix is composed of a fine-grained mixture of authigenic chlorite and white mica. Limonitic stains are common and a magnetite cement is locally present. In places cubes of pyrite are found in the matrix. The detrital grains commonly show marginal replacement by the matrix minerals.

A little epidote has been formed in greywackes lower in the sequence. It occurs scattered through the rocks and in veinlets, but mainly occurs as fine-grained aggregates enclosed in plagioclase. The plagioclase of these rocks is albite, whereas higher in the sequence it is generally oligoclase. This suggests that albitization of detrital oligoclase may have taken place in the deeper rocks, epidote being liberated during the reaction.

The *greywacke-conglomerates* are made up of large rounded or sub-rounded rock pebbles (averaging 4 mm in diameter, with a maximum diameter of 10 mm), together with smaller, commonly angular rock and mineral fragments, many of which are of sand size. The detritus is set in an iron-stained matrix of chlorite and white mica, which is much less abundant than in the greywackes. Locally the matrix is

coarser-grained and resembles greywacke. The mineral fragments are mainly of plagioclase and quartz, and the rock fragments comprise rock types similar to those occurring in the greywackes, especially porphyritic acid and intermediate rocks, chert (commonly ramified by thin quartz veinlets), argillite, siltite and greywacke. Fragments of plutonic rocks are absent.

The *silty argillites* are black and apparently massive in hand specimens, but in thin section they show alternating coarse- and fine-grained layers. These rocks are better sorted than the greywackes, and consist of silt-size fragments of quartz and plagioclase with fewer rock fragments, embedded in a matrix composed of authigenic chlorite and white mica with some iron oxide and parallel streaks of (?) carbonaceous material. The matrix is much more abundant than the detritus.

Contact Metamorphism of Sediments

The Uralla Beds adjacent to the granodiorite-adamellite body have been contact metamorphosed. North of the Uralla-Balala Road about 5 miles west of Uralla, where the rocks are relatively well exposed, biotite is characteristic of the hornfelses at least as far as half a mile from the contact, whereas cordierite is present as well in rocks in the inner parts of the aureole. In the south-eastern part of the area the relationships are similar but, in addition, spotted hornfelses have been encountered about half a mile from the contact. Therefore, there appears to be a zoning of the aureole similar to the zoning of contact metamorphosed argillaceous hornfelses recognized by Tilley (1924) in the Comrie area of the Perthshire Highlands. In the Uralla area, spotting has been observed only in the hornfelses derived from argillites, the greywackes probably being too coarse-grained.

Near the Uralla-Balala road, about 3 miles west of Uralla, highest grade hornfelses occur $\frac{3}{4}$ mile from the nearest contact. This is presumably the effect of an underlying apophysis from the main mass.

Petrography—Petrographic observations have been confined largely to the metamorphosed greywackes and argillites, since the altered greywacke-conglomerates observed show only a low grade of metamorphism, by virtue of their occurrence in the outer parts of the aureole. The higher grade hornfelses are fine-grained rocks consisting of granoblastic quartz, plagioclase, potash feldspar and minor cordierite, together with flaky biotite and

muscovite. Some of these rocks carry porphyroblastic garnet or granular andalusite as well. The low grade hornfelses consist mainly of quartz, plagioclase, sericite, chlorite and biotite. Chialstolite is present in some of the low grade hornfelses derived from argillite. The argillite hornfelses commonly show fine relic bedding and the lower grade greywacke hornfelses possess blastopsammitic textures.

Quartz is the most abundant mineral in the sedimentary hornfelses, generally forming a finely granular mosaic, although some larger relic grains are also commonly present. The quartz, which in places shows undulose extinction, generally carries inclusions of magnetite, apatite, biotite, muscovite and unidentified "dust". *Biotite* forms decussate aggregates, independent flakes, or incipient rounded blebs (depending on the grade of metamorphism), some grains being sieved with quartz. In some rocks the biotite flakes show parallel alignment. *Cordierite*, commonly partly converted to pinite, occurs as xenoblastic to elongated, rather ragged grains, many of which show a good cleavage. Inclusions of quartz, magnetite and biotite are common, and some cordierite grains show cyclic twinning in pseudohexagonal cross-sections.

Muscovite occurs as decussate aggregates, small disseminated flakes, and large plates sieved with quartz. Some has replaced biotite.

Potash feldspar occurs as small, xenoblastic grains, which are readily recognized after staining with sodium cobaltinitrite. It tends to be preferentially concentrated in certain areas of the rocks. *Plagioclase*, extensively kaolinized and sericitized, forms part of the granoblastic mosaic also. Owing to the alteration, its refractive indices were not measured.

Garnet forms xenoblastic, fractured, light pink porphyroblasts, commonly altering to (?) magnetite or chlorite along the cracks. It is generally free from inclusions except for a little apatite. The garnet has $n=1.812 \pm 0.003$, suggesting a composition of approximately 65–70 per cent almandine and 30–35 per cent spessartite (Winchell and Winchell, 1951, p. 487). *Andalusite*, a rare constituent, occurs as small, generally fresh, irregular and rounded grains, which have grown around the quartz. The andalusite is commonly pleochroic, the absorption being sharply variable within a single grain (cf. Winchell and Winchell, 1951, p. 522). The variable absorption and a lower refractive index distinguish the andalusite from possible hypersthene. The pleochroism scheme is:

X=deep pink, Y=Z=very pale green. Fine-grained (?) magnetite is commonly associated with this granular andalusite. In some of the low grade argillite hornfelses, *chialstolite* forms idioblastic prismatic porphyroblasts up to 2 mm across, basal sections of which show minute opaque inclusions arranged in a cruciform pattern. Finely granular iron oxide is also concentrated around the edges of the chialstolite crystals.

Accessory minerals in the sedimentary hornfelses include (?) *magnetite*, *zircon* and *apatite*.

Sequence of Metamorphic Changes—The initial metamorphic effect in the greywackes is the recrystallization of the authigenic chlorite and white mica, forming larger crystals, which may occur in clusters. In the argillaceous rocks "spots" of chlorite, white mica and opaque needles represent the first metamorphic effects. Among the weaker effects in both rock types is the formation of disseminated grains of (?) magnetite. Biotite is the next mineral formed, appearing first as incipient blebs, and it persists through all higher stages. Increase in biotite results in decrease in chlorite and white mica which, together with some of the magnetite, combine to form the biotite (Tilley, 1924, p. 29; Harker, 1932, p. 49). In the greywackes, the biotite and excess magnetite are more abundant in the areas formerly occupied by the matrix. In the argillites, biotite (together with fine-grained white mica) initially forms incipient blebs occurring between the spots. It gradually increases in amount as white mica decreases, and is joined by disseminated magnetite granules. In some of the argillite hornfelses chialstolite is formed at an early stage, being present in rocks which still show some weak spotting. The chialstolite tends to be concentrated in certain bands, possibly those rich in aluminous material and poor in chlorite (Tilley, 1924, p. 31; Harker, 1932, p. 49).

A higher stage of metamorphism is marked by the development of a granoblastic texture, a more complete crystallization of biotite, and the formation of cordierite. Garnet is locally present in the higher grade rocks, owing probably to local concentration of manganese (Tilley, 1926, p. 50).

Close to the contact the hornfelses contain abundant potash feldspar, somewhat less biotite than before, cordierite, plagioclase, and a little granular andalusite. Whether the original sediments contained sufficient potassium (in the authigenic white mica especially) to permit the

formation of potash feldspar by thermal processes, or whether the potash was introduced from the granodiorite, remains unknown in the absence of chemical evidence. These potash feldspar-rich hornfels also contain some muscovite, and close to the contact muscovite may be so abundant as to almost exclude potash feldspar. Its presence implies an introduction of at least water and fluorine from the granodiorite.

Contact Metamorphism of Igneous Rocks

Quartz Porphyries

Most of the information on these rocks comes from the large outcrop in the south-east of the area (Fig. 1). The metamorphosed quartz porphyries possess blastoporphyratic textures and consist of large relic phenocrysts (broken down to varying degrees) of quartz, plagioclase and occasional potash feldspar, set in a granoblastic groundmass consisting mainly of quartz and potash feldspar. In the outer parts of the aureole, the only mineralogical changes are the sericitization of the feldspar and the formation of chlorite, magnetite and a little brown and green biotite in the groundmass. However, higher grade rocks are much more extensively recrystallized, and carry small amounts of cordierite and granular andalusite. They may also contain a little muscovite, which locally forms large, poikiloblastic plates.

Porphyrites

The contact metamorphosed porphyrites are blastoporphyratic rocks, consisting of relics of former plagioclase phenocrysts set in a groundmass of plagioclase, secondary ferromagnesian minerals and, in some rocks, abundant calcite. The ferromagnesian minerals are blue-green fibrous actinolite (locally radiating), biotite and chlorite. The biotite is usually brown, rarely greenish, and is commonly partly altered to chlorite. A little magnetite is generally present, and some of the porphyrites carry minor muscovite and potash feldspar.

The Granodiorite-Adamellite

A body of granodiorite-adamellite occupies the central parts of the Uralla area. Xenoliths are abundant, especially in the marginal part of the mass, and veins of aplite are common.

Petrography—The granodiorites and adamellites are medium-grained rocks, without any obvious lineation. In thin section the rocks are seen to consist of quartz, orthoclase, plagioclase,

biotite, hornblende and minor pyroxene, together with accessory zircon, opaque minerals and apatite. The texture of the rocks is hypauto-morphic-granular and the average grain-size is 1 mm.

Quartz and *orthoclase* occur as anhedral grains filling the interspaces between the plagioclase, biotite and hornblende crystals. The quartz commonly shows undulose extinction and carries "dusty" inclusions. The orthoclase forms plates, 1 to 3 mm across, and is kaolinized, generally to a greater degree than the plagioclase. Some grains of orthoclase show carlsbad twinning. *Plagioclase* occurs as euhedral to subhedral tabular crystals averaging 2×1 mm in size. It has $\beta = 1.548$,* corresponding to a composition of An_{32} wt. per cent (Chayes, 1952), or An_{31} mol. per cent. Some plagioclase grains are slightly zoned from An_{37} mol. per cent (core) to An_{31} (margin). The plagioclase is twinned on the albite, carlsbad and pericline laws, and on combinations of these laws. Many grains are irregularly kaolinized and sericitized, especially along fractures, cleavages, and in some of the more calcic zones. In some of the granodiorites a second generation of plagioclase occurs as small, well-formed grains averaging 0.75×0.5 mm.

Biotite occurs as platy crystals, which are strongly pleochroic from straw-yellow (X) to deep fox-brown (Y,Z); $X < Y = Z$. Sections perpendicular to the (001) cleavage average 0.75×0.5 mm. The 2V (—) is generally 0, but may be a few degrees, and $\beta \approx \gamma = 1.648 \pm 0.003$. The biotite is commonly moulded on, or appears to replace, hornblende. Some biotite and biotite-hornblende aggregates are present. Pleochroic haloes around inclusions of zircon commonly occur in the biotite.

The biotite is partly altered to chlorite, but the conversion is very irregular. Some biotite flakes are completely pseudomorphed by chlorite, whereas others are unaltered. The by-products of the transformation are (?) *magnetite*, which forms anhedral grains in the biotite and chlorite especially along cleavages, and *potash feldspar*, which forms minute granules inside and along the margins of the biotite and chlorite flakes. Staining with sodium cobaltinitrite is necessary for the recognition of this finely granular feldspar. Contrary to what might be expected, the potash feldspar granules are not confined to the chlorite; in places they are absent from the chlorite and yet cover the associated biotite.

* All refractive indices were measured on oriented grains by the immersion method in sodium light.

Hornblende forms euhedral to ragged or fibrous anhedral grains varying considerably in size. The average prismatic section measures 0.75×0.5 mm. Both aggregates and independent grains are present, and parallel intergrowth with biotite is common, especially at the margins of the hornblende grains. Twinning, with (100) as twin-plane, is common, lamellar twins predominating over simple twins. The hornblende is weakly absorptive, with $X < Y < Z$, and is pleochroic with X =very pale brown-green (almost colourless), Y =pale brown-green, Z =slightly darker brown-green. Its refractive indices are $\alpha=1.636$, $\beta=1.650$, $\gamma=1.657$ (all ± 0.003); $\gamma-\alpha=0.021$. The $2V$ is large and most of the hornblende is optically negative. However, a few grains show positive signs, although otherwise apparently identical with the normal hornblende. The relatively low refractive indices, large $2V$ and weak absorption suggest that the hornblende is relatively rich in MgO and poor in FeO (Sundius, 1946, pp. 26, 29; Winchell and Winchell, 1951, pp. 434-436). The hornblende shows local alteration to chlorite, magnetite and rare carbonate.

Proxene never exceeds one per cent of the rocks by volume, but is present in most of the granodiorite sections examined. It is rare in the adamellites. *Orthopyroxene* occurs as aggregates up to 3 mm across enclosed by hornblende and biotite, as cores in individual hornblende crystals, or rarely as separate grains. It is colourless and its composition is somewhat variable, as indicated by refractive index

measurements, β varying from 1.686 ± 0.003 to 1.695 ± 0.003 . These figures correspond to compositions of Of_{18} and Of_{25} mol. per cent, respectively (Poldervaart, 1950, p. 1076). This bronzite is probably xenocrystal, since such a magnesian orthopyroxene is unlikely to have crystallized from an acid magma. *Clinopyroxene* is rarer, and forms smaller grains than the orthopyroxene. It is generally colourless and anhedral, except for occasional pale green, stocky anhedral grains enclosing residuals of orthopyroxene.

Accessory minerals consist of zircon, (?) magnetite and apatite. The zircon occurs as euhedral to rounded grains and less commonly, as aggregates. Some crystals are zoned. The zircon contains minute inclusions of apatite, (?) magnetite and biotite. The accessory magnetite is distributed through the rocks as irregular and rounded grains. The apatite occurs as microlites, slender elongated prisms, or as larger euhedral stocky prisms commonly associated with ferromagnesian minerals. Some grains are associated with zircon in aggregates. The apatite has $\varepsilon=1.637 \pm 0.002$ and $\omega=1.640 \pm 0.002$, so that it is probably fluorapatite (Winchell and Winchell, 1951, p. 198).

Modal Composition—Modes of selected specimens of granodiorite and adamellite are presented in Table 2. They show that even though the orthoclase:plagioclase ratio varies considerably, no rock lies outside the granodiorite-adamellite field. All the rocks are relatively rich in ferromagnesian minerals, and

TABLE 2
Modal Composition of Uralla Granodiorites and Adamellites¹

Number ²	Quartz	Orthoclase	Plagioclase	Biotite	Hornblende ³	Accessory Minerals	Colour Index
S1003	20.1	6.3	42.7	12.7	17.8	0.4	30.9
S1001	15.4	12.2	46.6	16.6	9.2	—	15.8
S994	26.6	11.1	41.2	12.9	8.1	0.1	21.1
S1005	25.6	13.2	38.1	17.1	6.0	—	23.1
S995	17.0	16.5	43.3	12.8	10.2	0.2	23.2
S997	23.4	16.5	36.1	15.4	8.5	0.1	24.2
S996	24.6	19.0	38.2	11.1	6.9	0.2	18.2
S1009	26.9	18.0	35.1	14.2	5.4	0.4	20.0
S1015	22.1	19.8	33.1	16.6	7.6	0.8	25.0
S1016	25.9	23.5	38.7	10.2	1.7	—	11.9
S1012	24.3	21.2	30.6	17.0	6.3	0.6	23.9
S1010	34.0	26.8	29.8	7.2	2.0	0.2	9.4
S1014	24.2	28.3	30.7	13.6	3.2	—	16.8
S1011	26.0	28.6	28.1	12.2	5.0	0.1	17.3
S1017	22.2	37.6	30.7	6.1	3.2	0.2	9.5

¹ Analyses made with Swift Automatic Point-Counter; slides stained for potash feldspar with sodium cobaltinitrite.

² Microslide catalogue numbers, Geology Department, University of New England.

³ Including pyroxene where present (always less than 1 vol. per cent).

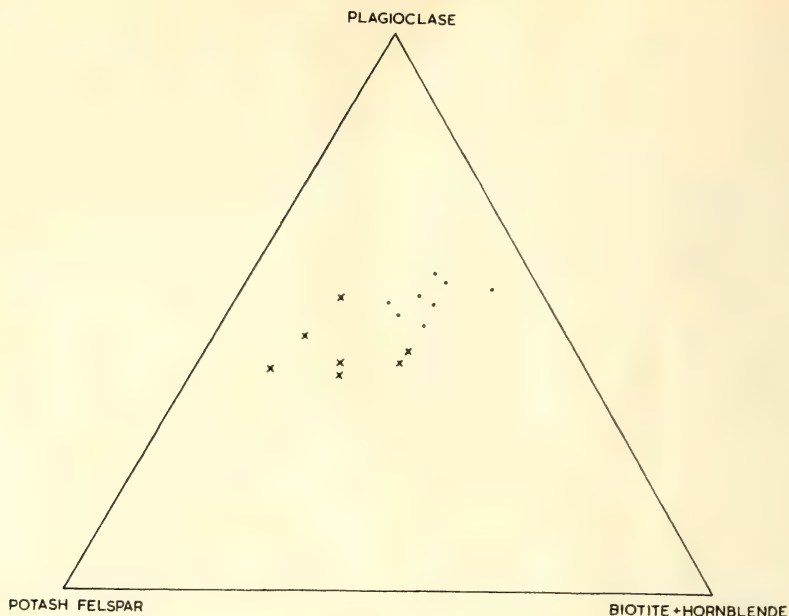


FIG. 3
Feldspar and ferromagnesian mineral content of Uralla granodiorites (dots) and adamellites (crosses) plotted to show variations

most contain more biotite than hornblende. The modes are arranged in order of increasing orthoclase: plagioclase ratio. This ratio varies in such a way that there is a gradation from plagioclase-rich granodiorites, through rocks very close to the granodiorite-adamellite boundary, to orthoclase-rich adamellites. The first eight modes in Table 2 represent granodiorites; the last seven represent adamellites. The granodiorites generally contain more ferromagnesian minerals than the adamellites, although the distribution is not regular. These relationships are shown diagrammatically in Fig. 3.

The localities of the specimens included in Table 2 are shown in Fig. 1, except for S995, which occurs near the eastern contact, west of Arding, some four miles north of the area shown in Fig. 1. The granodiorites occur in the marginal parts of the mass and the adamellites generally occur in the central area. The volume of adamellite appears to exceed the volume of granodiorite. The modal analyses show, therefore, that there is a probable gradation from marginal granodiorite to central adamellite, with a corresponding decrease in colour index, although the latter quantity is subject to abrupt local variation.

Xenoliths—The granodiorite-adamellite body contains numerous xenoliths, which are more

abundant towards the margins of the mass. The most common type of xenolith, where least reconstituted, consists of fine-grained, granular basic plagioclase, orthopyroxene, clinopyroxene, and minor (?) magnetite, together with a little hornblende and biotite, which appear to have formed at the expense of part of the pyroxene. The assemblage pyroxene-basic plagioclase suggests that the xenoliths are recrystallized fragments of basic, or possibly intermediate, igneous rocks.

Various stages of reconstitution are shown by these xenoliths. Simple recrystallization of the original minerals, together with incipient conversion of the pyroxene to hornblende and biotite, characterize the least altered xenoliths. A more advanced stage of reconstitution is marked by increased replacement of pyroxene by hornblende and biotite, and of hornblende by biotite. Some of the hornblende and biotite grains enclose residual cores of pyroxene, and others are sieved with granular plagioclase or with granular quartz released during the breakdown of pyroxene. These transformations have been accompanied by conversion of the original basic plagioclase to a more sodic variety, namely sodic andesine. The completely reconstituted xenoliths also contain interstitial quartz and orthoclase, so that they are identical with the surrounding rock, except for a higher content of

ferromagnesian minerals, a finer grain-size, and a rather higher apatite content. The compositions of the biotite, hornblende, plagioclase and apatite inside and outside the reconstituted xenoliths appear to be identical, as indicated by refractive indices (Table 3).

"Coronas" or "reaction envelopes", consisting of large, generally sieved crystals of biotite and hornblende, commonly rim the xenoliths, extending into them along fractures. The "reaction envelopes" appear to have resulted from marginal reaction between the xenoliths and the magma, large crystals having been formed probably because of the freedom of growth just outside the xenoliths and near their disintegrating margins, compared with restricted growth inside the compact xenoliths.

Disintegration of many of the xenoliths has released their constituent grains into the host magma, forming xenocrysts or xenocrystal aggregates in the granodioritic rocks. The arrested disintegration process is plainly visible, in that "streams" of crystals and aggregates of ferromagnesian minerals leading away from partly disintegrated xenoliths and especially from the "reaction envelopes", can be seen.

A few quartz-rich xenoliths have been examined. These consist of a mosaic of quartz grains, between which small amounts of hornblende, biotite, plagioclase, orthoclase, apatite and (?) magnetite have crystallized. A "reaction envelope", consisting mainly of hornblende with a little biotite, is present.

Petrogenesis — The granodiorite-adamellite mass was almost certainly emplaced by the intrusion of magma, rather than by granitization *in situ*. In places it shows cross-cutting relationships with the north-striking sedimentary rocks (Fig. 1), and no gradational contacts have been observed. A normal contact metamorphic aureole occurs adjacent to the mass. In addition, the surrounding sediments have not

undergone regional metamorphism, so that the terrain is not of the type in which granitization typically occurs (cf. Walton, 1955).

The rising magma has incorporated fragments of what appear to have been basic (possibly intermediate) igneous rocks. The orthopyroxene ($\beta=1.707 \pm 0.003$, Of_{35} mol. per cent) of these xenoliths is similar to the orthopyroxene ($\beta=1.709 \pm 0.003$) occurring as phenocrysts in a porphyritic microdiorite dyke outcropping in the west of the Uralla area. These xenoliths, therefore, may have been extracted from a similar rock. The irregular aggregates of bronzite, partly replaced by hornblende and biotite, which occur locally in the granodiorite, have probably resulted from the disintegration of xenoliths, but the nature of the rock from which they were derived is unknown. The quartz-rich xenoliths possibly have a sedimentary parentage.

The addition of xenocrystal material to the magma has caused the rocks in the marginal parts of the mass, where xenoliths are more abundant, to become more melanocratic and richer in plagioclase. In addition, the magma has probably been chemically enriched in iron, magnesium and calcium released during the reconstitution of the xenoliths, forcing more hornblende, biotite and plagioclase to crystallize from the magma (Nockolds, 1933). It may also have been depleted in potassium and sodium, required to form biotite and plagioclase in the xenoliths. These chemical adjustments would aid the mechanical "strewing" process in causing the marginal rocks to approach a granodioritic composition.

The observed gradation from marginal, more melanocratic granodiorite to central, more leucocratic adamellite is believed to have resulted from the above contamination process rather than from fractionation brought about by crystallization from the edges of the mass

TABLE 3

Similarity in Refractive Index between Minerals in Reconstituted Xenoliths and Minerals in Host-rocks

Mineral	In Host-rock		In Reconstituted Xenolith	
	R.I.	No.	R.I.	No.
Plagioclase	$\beta=1.547 \pm 0.002$	S1021	$\beta=1.545 \pm 0.002$	S1021
Hornblende	$\beta=1.649 \pm 0.003$	S1019	$\beta=1.650 \pm 0.003$	S1019
	$\beta=1.650 \pm 0.003$	S1021	$\beta=1.650 \pm 0.003$	S1021
			$\beta=1.649 \pm 0.003$	S1024*
Biotite	$\gamma=1.648 \pm 0.003$	S1019	$\gamma=1.644 \pm 0.003$	S1007
Apatite	$\epsilon=1.637 \pm 0.002$	S1024	$\epsilon=1.635 \pm 0.002$	S1023
	$\omega=1.640 \pm 0.002$		$\omega=1.638 \pm 0.002$	

* From "reaction envelope".

inwards. According to Bowen (1928, p. 22) such a process is unlikely to cause significant fractionation in a cooling intrusion, owing to the fact that "the rate of diffusion of temperature is . . . at least 4000 times as great as the rate of diffusion of substance." Moreover, the composition of the plagioclase and hornblende, as indicated by refractive index measurements, does not vary across the Uralla intrusion.

The fact that the orthopyroxene (and probably the clinopyroxene) in the xenoliths is rich in magnesium relative to iron probably accounts for the magnesian nature of the hornblende in the granodiorite-adamellite, since some has directly replaced pyroxene and some has probably crystallized as a result of addition of magnesium to the magma from the xenoliths.

The *biotite-chlorite reaction* in the granodiorite-adamellite (and the xenoliths) is worthy of special mention, since the effects are well displayed in the Uralla rocks. Similar phenomena have been observed by Chayes (1955) in adamellites from the Sierra de Guadarrama. Chayes (1955, p. 78) has shown from stoichiometric considerations that much more potash feldspar should be visible in the chlorite and biotite grains than is actually present. His conclusion is supported by the writer's observations on the Uralla rocks. The potash appears to have migrated from the site of the reaction and probably entered the late-stage potassic liquids. This scarcity of potash feldspar is convincingly shown by a specimen of quartz monzonite collected a few miles west of the area shown in Fig. 1. The rock has undergone extensive deuteric alteration and all the biotite has been completely pseudomorphed by chlorite, with minor (?) magnetite. Despite this complete transformation, potash feldspar granules are very rare, although some dot the margins of the chloritized flakes.

Other Igneous Rocks

Quartz Porphyries

Unmetamorphosed quartz porphyries occur mainly in a belt running through the western part of the area. In thin section they are seen to consist of phenocrysts of quartz, altered orthoclase and altered sodic plagioclase, set in a variable fine-grained groundmass of quartz and alkali feldspar. In some types, large altered spherulitic growths radiate from the phenocrysts.

Porphyritic Pyroxene-Microdiorite

Dykes of porphyritic pyroxene-microdiorite occur in the west of the area. These rocks

consist of phenocrysts of plagioclase, orthopyroxene (commonly zoned and schillerized), and clinopyroxene, set in a groundmass of plagioclase; (?) magnetite, apatite and zircon are the accessory minerals. The orthopyroxene is optically negative and has $\beta=1.709 \pm 0.003$ and $\gamma=1.713 \pm 0.003$, these properties corresponding to a composition of $\text{Of}_{3.7}$ mol. per cent (Poldervaart, 1950, p. 1076). A little biotite and potash feldspar occurs in the groundmass.

Basaltic Rocks

Outliers of olivine basalt, associated with small, near-surface intrusions of teschenite, occur in the Uralla area (Fig. 1). The basalt is probably of Oligocene age (Voisey, 1957, p. 130).

The *olivine basalts* may be divided into two types:

(i) strongly porphyritic types, which consist of phenocrysts of altered, anhedral to subhedral olivine (averaging 0.25 mm across), stout, sometimes corroded, euhedral labradorite (averaging 0.5 mm long), and a little anhedral clinopyroxene, set in a fine-grained pilotaxitic groundmass of labradorite, with subordinate olivine, clinopyroxene, (?) magnetite, apatite, analcite, and secondary limonite;

(ii) slightly porphyritic types (also pilotaxitic) which are very fine-grained, and consist of a few relatively large clinopyroxene phenocrysts (up to 1×0.75 mm) set in a very abundant groundmass of labradorite, olivine, clinopyroxene, (?) magnetite, apatite and analcite, with secondary chlorite and limonite.

The *teschenite* is composed mainly of elongated, lightly kaolinized labradorite laths (averaging 1 mm in length) and titaniferous diopsidic clinopyroxene grains (averaging 1–2 mm across), which exhibit intergranular, sub-ophitic, or more rarely, ophitic textural relationships. Anhedral to subhedral, fractured grains of olivine (averaging 0.75 to 1 mm across) are less abundant, and are invariably partly altered to iddingsite. Apatite, (?) magnetite and interstitial analcite are always present. Secondary minerals include chlorite and limonite.

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The Nature of Light Propagation

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ABSTRACT—By making clear distinction between the conventional measures and the proper measures of space and time intervals it is possible to achieve a consistent and physically interpretable approach to special relativity. This approach implies the further distinction between the conventional measure, v , of relative velocity and its "clocked" measure w . It is suggested that Einstein's light velocity principle implies the relationship:

$$w=c\left(\sqrt{\frac{1+v/c}{1-v/c}}-1\right),$$

thus meeting the claim that clocked velocities greater than c have been observed and are required by nuclear and quantum theory.

It is further shown that the Lorentz transformation forms a direct and necessary mathematical link between Einstein's light velocity principle and the mass-energy equivalence formula, suggesting that the nature of light propagation may be physically related to the mass-energy transformation phenomenon.

Finally the intuitive (commonly accepted) approach to reflected light rays is shown to result in a hitherto unsuspected contradiction which is absent in the alternative interpretation proposed.

1. Introduction

In a previous communication (Prokhovnik, 1960*b*) it was suggested that the interpretation, there proposed, of the Lorentz transformation leads to a method of synchronizing clocks in relative motion and hence to the possibility of investigating experimentally the nature of light propagation between observers in relative motion. Distinction was also made between the "clocked" velocity of a body in relative motion and the measure of this velocity when determined according to Einstein's definitions. It will be shown that the relation between these two measurements depends precisely on the nature of light propagation; and hence that the experimental investigation of this relation can provide an important test of our approach and of its underlying assumptions, in particular, Einstein's light-velocity principle.

The basic principles and definitions involved in this discussion are as previously (Prokhovnik, 1960*a*; 1960*b*),* viz.:

- I. Equivalence of inertial systems.
- II. Constancy of velocity of light for all inertial systems.
- III. The independence of the mode of light propagation between observers in relative motion, to the direction of the propagation.

- (i) Definition of synchronism.
- (ii) Definition of the "time" of an event.
- (iii) Definition of space interval.
- (iv) Definition of relative velocity.
- (v) Definition of synchronism of clocks in relative motion consequent on III.

As before we will be discussing measurement relationships between two observers A and B receding from one another with relative velocity v (according to (iv)), and carrying similar clocks which were synchronized at $t_A=t_B=0$ during their spatial coincidence. The same terminology as previously will apply to the measurement of an event. Thus if at time t_A^1 the observer A transmits a light signal which reflects an event and returns to him at t_A^3 , we will denote by t_A' the time of reflection of the event according to A 's time-scale. t_A' cannot be considered as being necessarily synonymous with the "time" defined in (ii); its value must be consistent with, and should be deducible from the principles assumed, that is, I, II and III. The definition (ii), on the other hand, is independent of the principles and leads to the measure

$$t_A^m = \frac{1}{2}(t_A^1 + t_A^3) \dots\dots\dots (1)$$

such that

$$c(t_A^m - t_A^1) = c(t_A^3 - t_A^m) = vt_A^m \dots\dots\dots (2)$$

The relation between t_A' and t_A^m is developed in paper A; however, the relevant argument requires a slight refinement, which does not affect its conclusions, though it involves making

* Henceforth, provided the context is clear, these two papers will be referred to as A and B respectively. The basic assumptions are presented formally in paper A.

a distinction between the "clocked" relative velocity and the measure of this velocity according to (iv). This distinction is clearly similar to that relating to time measurements as discussed above. It is further shown that the argument in paper B leads to a unique relation between these two measures of the relative velocity and that this relation is a necessary consequence of the Lorentz transformation. It will be seen that this implies some interesting links between the nature of light propagation and the mass-energy equivalence relationship.

2. The Clocked Relative Velocity

This measure of B 's velocity relative to observer A is obtained by clocking the position of B at two points in A 's inertial system. This requires that at each of these points there be an observer who is stationary in A 's inertial system and whose clock is synchronous with A 's clock, according to (i). It is seen that the corresponding space and time intervals measured by the two observers are the proper intervals in A 's inertial system. Hence the clocked relative velocity, w , so obtained can be considered as the proper relative velocity of B in A 's inertial system.

We have at present no reason to assume any particular relationship between w and the measure v determined according to (iv). However, whatever relationship obtains between w and v in A 's inertial system, must, by the principle of relativity (I), also hold in B 's inertial system, and since in accordance with this principle, the measurement v is the same for both observers A and B , therefore the measurement w will also be the same whether obtained as B 's clocked velocity in A 's inertial system or vice versa. This can be considered as a direct consequence of I, since w , as well as v , depends only on a mutual and symmetrical relationship between A and B .

3. The Relation between w and v

Consider now as in paper A, Part 3, a light signal transmitted by A at t_A^1 , reflecting a clock reading t_B^1 and returning to A at t_A^3 . Let the time of reflection, according to A 's time-scale, be denoted by t_A^2 . Then according to A the proper distance separating A and B is wt_A^1 at the departure of the signal and wt_A^2 at its arrival at B . Hence the distance travelled by the signal on its outward journey cannot be less than wt_A^1 nor greater than wt_A^2 , though it may have some intermediate value between these

two bounds. If this distance be denoted by d_{AB} then

$$d_{AB} = wt_A^1 + k_{AB}(wt_A^2 - wt_A^1) = c(t_A^2 - t_A^1) \quad \dots (3)$$

since the signal travels with velocity c relative to A in the interval t_A^1 to t_A^2 , and where k_{AB} is a constant which may depend on w and $0 \leq k_{AB} \leq 1$. Similarly, for the return journey

$$d_{BA} = wt_A^2 + k_{BA}(wt_A^3 - wt_A^2) = c(t_A^3 - t_A^2) \quad \dots (4)$$

where k_{BA} may depend on w and $0 \leq k_{BA} \leq 1$.

As before we propose, in accordance with III, that

$$k_{AB} = k_{BA} = k \text{ (say).}$$

(3) and (4) then lead to the result

$$(t_A^2)^2 = t_A^1 t_A^3 \quad \dots \dots \dots (5)$$

exactly as in paper A, and hence also to the relationships

$$t_A^2 = t_A^m \sqrt{1 - \frac{v^2}{c^2}} \quad \dots \dots (6)$$

that is

$$t_B^2 = t_A^m \sqrt{1 - \frac{v^2}{c^2}} \quad \dots \dots (7)$$

if the clocks associated with A and B have remained synchronous.

It is seen that the introduction of w makes d_{AB} and d_{BA} more precise and theoretically measurable. They are the proper space intervals, in A 's inertial system, separating the source and destination of a light-ray. However, the argument is equally valid from B 's viewpoint; for provided only that B 's clock runs at a constant rate relative to A 's,* then the argument is not affected when considered in terms of B 's corresponding clock readings and proper space intervals.

Combining (6) with (2) leads to

$$t_A^2 = t_A^1 \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \quad \dots \dots \dots (8)$$

and

$$t_A^3 = t_A^2 \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \quad \dots \dots \dots (9)$$

* Even if we assume a one-sided time dilatation, then this provision is satisfied for the case of uniform relative motion between A and B . However, we note that the space interval separating A and B is also a mutual symmetrical relationship between these two observers; and that this symmetry is fully consistent with the conclusion that the synchronism of clocks A and B is not affected by their uniform relative motion, such that an identifiable space interval (e.g. d_{AB}) separating A and B , will have the same proper value whether measured in B 's inertial system or in A 's.

Thus (3) and (8) provide two expressions for t_A^r/t_A^1 , whose elimination yields

$$w \left(1 - k + k \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \right) = c \left(\sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} - 1 \right) \dots (10)$$

It is seen that this relation between w and v depends on the nature of k , the "light propagation parameter". However, if, as in paper A, no distinction is made between w and v , then k is restricted to a unique function of $\frac{v}{c}$. This is the consequence of equating w and v , and this possibility is not precluded, nor is it assumed, by our introduction of w . The argument is thereby generalized so that k remains unrestricted (within its limits) in the absence of further evidence relating to its nature.

The key result (5) is independent of either w or v . It depends only on the assumption that the space interval separating A and B is proportional to A 's clock-reading (or alternatively to B 's clock-reading). In this sense, therefore, the original argument of paper A is quite valid, albeit insufficiently general when viewed from its further development.

4. The Value of k

In paper B, the result (7) is extended to space-interval measurements. The relationships obtained in this way are precisely those of the Lorentz transformation and this would appear to affirm the consistency of our interpretation of the transformation co-ordinates. It is suggested that our approach is the only one which gives physical meaning to the reciprocity property of the transformation.

However, the extension of (7) in this way requires a specific assumption, not previously invoked, regarding light propagation—namely, that the velocity of a light ray has the value c for all inertial systems. This is of course Einstein's second principle and it leads to equations (10), (11) of paper B in the following way.

Consider an event E , collinear with the observers A and B , occurring at a location stationary relative to B and hence at a fixed distance x_B^m according to B . The event is reflected by two light rays, one transmitted by observer A at t_A^1 and the second by observer B .

The first ray reaches B at $t_A^1 \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}}$, accord-

ing to (8), and, in conformity with Einstein's light-velocity principle, it takes an additional time $\frac{x_B^m}{c}$ to reach E , since B and E are separated

by a fixed space interval, x_B^m . Hence on A 's time-scale the event at E is reflected at t_A^{r*} , where

$$t_A^{r*} = t_A^1 \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} + \frac{x_B^m}{c}, \dots (11)$$

Similarly on reflection the ray returns to B at $t_A^{r*} + \frac{x_B^m}{c}$ and thereafter behaves like a light signal from B to A , so that using (9), the ray returns to A at t_A^3 where

$$t_A^3 = \left(t_A^{r*} + \frac{x_B^m}{c} \right) \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}}, \dots (12)$$

Now (11) and (12) must be valid for, at least, all $t_A^1 \geq 0$; hence, in particular, for $t_A^1 = 0$ when A and B are spatially co-incident, (11) becomes

$$t_A^{r*} = \frac{x_B^m}{c}.$$

That is, the distance apparently traversed by the light-ray, on its outward journey to E , is x_B^m —the space-interval separating A and E at the time of transmission, t_A^1 . Thus the assumption of Einstein's light-velocity principle demands a specific mode of light propagation equivalent to taking $k=0$ in the context of the equations (3) and (4).

The principle II is indissolubly linked also with the Lorentz transformation; the combining (as in paper B) of (11) and (12) with the simpler expressions for B 's measurements yield the transformation directly.

An alternative assumption regarding light propagation, and involving therefore a different value of k , leads inevitably to a different transformation, which would still however reflect the principle of relativity and embody the formula (7). For instance, if we were to assume

* Note that the circumstances here are different to those which led to equation (8); hence they lead to a different relationship between t_A^r and t_A^1 , etc.

that a light-ray always has the velocity c with respect to its source, then instead of (11) and (12) we would have*

$$t_A^r = \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \left(t_A^1 + \frac{x_B^m}{c} \right) \dots (13)$$

and

$$t_A^3 = \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \left(t_A^r + \frac{x_B^m}{c} \right) \dots (14)$$

Assuming that (13) is valid for $t_A^1=0$, it is seen that this is equivalent to the case, $k=1$. The symmetry of these relationships appears to match that of (11) and (12), yet they lead to

$$t_A^m = \frac{t_B^m}{\sqrt{1 - \frac{v^2}{c^2}}} + \frac{x_B^m}{2c} \left(\sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} - 1 \right)$$

$$x_A^m = \frac{vt_B^m}{\sqrt{1 - \frac{v^2}{c^2}}} + \frac{x_B^m}{2} \left(\sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} + 1 \right)$$

so that

$$x_B^m = \frac{2(x_A^m - vt_A^m)}{\sqrt{1 - \frac{v^2}{c^2}} + 1 - \frac{v}{c}}$$

and

$$t_B^m = t_A^m - \frac{x_A^m}{v} \left(1 - \sqrt{1 - \frac{v^2}{c^2}} \right).$$

This transformation is neither symmetrical nor reciprocal, nor does it satisfy the invariance relationship

$$(x_A^m)^2 - (ct_A^m)^2 = (x_B^m)^2 - (ct_B^m)^2.$$

It would appear therefore that the mathematical symmetry and elegance of the Lorentz transformation are an expression not only of the principle of relativity but also of the assumption that the velocity of a light-ray is the same for *all* inertial systems, requiring that $k=0$. Thus the Lorentz transformation gives faithful expression to Einstein's concepts in terms of his definitions.

* By considering that the light-ray takes time $\frac{x_B^m}{c}$ to reach a point A' , distant x_B^m from A and stationary relative to A . Thus A' bears a similar spatial relationship to E as A does to B , and so (8) and (9) are applicable.

5. Experimental Implications

On putting $k=0$ in (10) we obtain

$$w = c \left(\sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} - 1 \right) = v \left(1 + \frac{1}{2} \frac{v}{c} + \frac{1}{2} \frac{v^2}{c^2} + \dots \right) \dots (15)$$

Thus w differs from v by $\frac{1}{2} \frac{v^2}{c}$ to the first order of magnitude. Such a difference should be experimentally detectable for velocities of say $\frac{c}{1000}$ relative to an observer. (15) may therefore provide a criterion for an experimental test of the underlying theory and its assumption.

However, there already appears to exist experimental and theoretical evidence supporting the validity of (15). The fact that special relativity appears to place an upper limit to the velocity of a particle has been challenged by nuclear physicists who claim to have detected clocked velocities greater than c . In particular, Heisenberg (1958) observes that the relativistic restriction on the magnitude of velocities leads to unresolved difficulties in connection with the uncertainty relations of quantum theory; and that "This state of affairs has as its practical consequence the fact that in attempting to arrive at a mathematical formulation of the interactions of the elementary particles, we shall always encounter infinite values for energy and momentum, preventing a satisfactory mathematical statement". The distinction between w and v expressed by (15) resolves this apparent contradiction, since w has no upper bound even though v has, as is inevitable from its definition; and $w \rightarrow \infty$ as $v \rightarrow c$.

The clocked velocity of a light-ray travelling between a source and destination, stationary in the same inertial system, has been determined to a high degree of accuracy. It would also be of interest to determine a light-ray's clocked velocity when its source and destination are in relative motion. If the synchronism of clocks associated with two observers A and B is not affected by their uniform relative motion, then such a measurement, for a light-signal travelling from A to B , could be based on A 's clock-reading on departure of the signal and B 's clock-reading coincident with its arrival at B . These times, together with a determination of the clocked relative velocity, would then be sufficient

to determine the light-signal's clocked velocity. Dingle (1959) has actually proposed such an experiment as a test of Einstein's light velocity principle.

6. The Validity of Einstein's Second Principle

The Lorentz transformation is based on a specific assumption regarding light propagation ; it cannot be derived without assuming that a light-ray has the same velocity for all inertial systems. This assumption certainly appears strange and incomprehensible in terms of classical concepts ; nevertheless, it has a considerable theoretical and experimental basis.

Many relativists consider that the invariance relationship

$$x^2 + y^2 + z^2 - c^2 t^2 = x'^2 + y'^2 + z'^2 - c^2 t'^2 \quad (16)$$

is a necessary corollary of the principle of relativity, and use (16) to deduce the Lorentz transformation. In fact, however, (16) also assumes the value of c of a light-ray's velocity for each of two inertial systems. It is inevitable, therefore, that this assumption should underlie the Lorentz transformation if it is to satisfy (16).

Yet it is not the elegance of (16) but of the Maxwell Equations which provided Einstein with the firmest support for his second principle. The invariance of these equations for all inertial systems requires the validity of the Lorentz transformation and hence of its underlying assumptions, and, in fact necessarily, these equations already imply that the constancy of c has universal validity. The power and experimental success of the Maxwell equations provided a powerful argument for the validity of Einstein's assumptions.

Later the astronomical evidence of de Sitter (1913) and others seemed to provide further support for Einstein's second principle. This evidence suggests that the propagation of light is independent of the velocity (relative to the light-ray's destination) of its source and hence that the apparent path of a light ray depends on the space interval separating source and destination at the instant of emission. As we have seen, this assumption is equivalent to taking $k=0$, which is basic to the Lorentz transformation.

The principle II is also mathematically expressed by the relativistic composition of velocities formula, which guarantees that a velocity of c for a given inertial system transforms to the same value for any other inertial system. This formula is an immediate consequence of the Lorentz transformation and by combining it (e.g. Møller, 1952) with Newton's first and second laws (conservation and rate of change of momentum), it leads in turn to relativistic dynamics and the mass-energy equivalence relationship

$$E = mc^2 \quad \dots\dots (17)$$

This relationship is therefore mathematically linked with the light-velocity assumption ; and the too-dramatic confirmations of (17) in recent years provide perhaps the strongest experimental evidence that light and matter have remarkable properties, as yet, little understood, but nevertheless correctly postulated in Einstein's principles. The mathematical link suggests also a physical link between the laws underlying light propagation and mass-energy transformations.

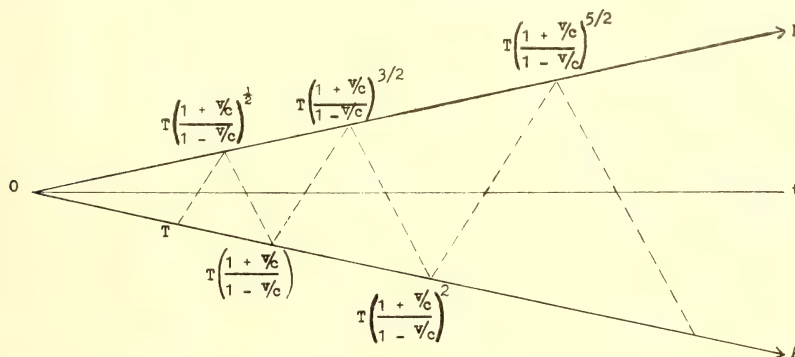


FIG. 1

Times of reflection, according to III, of a light ray travelling to and fro between receding observers A and B . The line Ot represents the common time-scale. The distance, in a direction normal to Ot , between OA and OB and corresponding to a given value of t is then proportional to the proper space-interval (according to either observer) separating A and B at the given time

There exists further evidence, independent of our approach, that the mass-energy relationship is linked explicitly with the propagation of light principle. According to Whittaker (1953) the relationship (17), or a very similar one, was proposed a number of times in the pre-relativity era, as a deduction of electromagnetic or radiation phenomena; and more recently, Synge (1954) has associated relativistic dynamics with de-Broglie wave theory by a four dimensional application of Hamilton's principle. It is suggested therefore that the experimental investigation of light propagation, leading to a deeper understanding of Einstein's second principle, may also help us to decipher further the significance of mass-energy equivalence. And since both of these phenomena have relevance to many aspects of modern physics, the amplification of relativity theory and of its underlying assumptions could have signal significance.

7. The Behaviour of a Reflected Light-Ray

The adoption of the hypothesis III has as its consequence the inequality of the out and return paths of a light-ray travelling between observers in relative motion. This is expressed by the relations (5), (6), (7) and by the figure in paper A which is reproduced as Figure 1.

III can be considered as a corollary of the relativity principle, I, since it is based on the idea that neither of two uniformly receding observers *A* and *B* can be considered as having a privileged status; and hence that the law of propagation of a light-ray travelling from *A* to *B* applies equally to a light-ray travelling from *B* to *A*. As is seen in Figure 1, this leads to a

sequence of reflection times which obeys the same law in the inertial system of either observer; and which provides a simple interpretation of the reciprocity of the Lorentz transformation.

However, the inequality of the out and return paths appears contrary to "common sense". For consider these light-paths from *A*'s intuitive standpoint. The reflection on *B* apparently occurs at a fixed point relative to *A* and hence the return path should be from this fixed point back to *A*, and should be equal to the outward path mapped on *A*'s inertial system. Thus according to *A* the time of reflection at *B* is given by the t_A^m of definition (ii) and so a sequence of such reflections might be represented as in Figure 2, where

$$\begin{aligned} t_A^2 - t_A^1 &= t_A^3 - t_A^2, \\ t_A^4 - t_A^3 &= t_A^5 - t_A^4, \text{ etc.} \end{aligned}$$

Now from *B*'s standpoint, any reflection at *A* should similarly take place midway, on *B*'s time-scale, between a pair of consecutive appearances of the light-ray at *B*; that is, according to Figure 3, where

$$\begin{aligned} t_B^3 - t_B^2 &= t_B^4 - t_B^3 \\ t_B^5 - t_B^4 &= t_B^6 - t_B^5, \text{ etc.} \end{aligned}$$

It is seen, by comparing Figures 2 and 3, that the time-scales of observers *A* and *B* cannot be reconciled with regard to their timing of the events 1 to 7. Equal intervals on *A*'s time-scale are unequal on *B*'s and vice-versa. This is not explicable even by assuming time dilatation; it could only be explained by assuming that *B*'s clock runs alternatively fast and slow relative to *A*'s and vice-versa.

Thus the alternative to the hypothesis III and Figure 1 yields two time-scales which

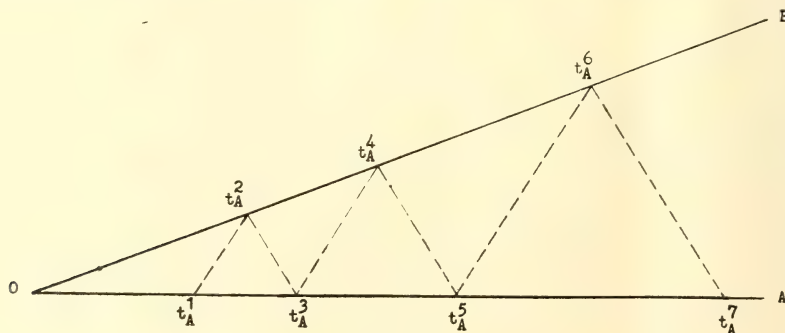


FIG. 2

Times of reflection, according to *A*'s intuitive standpoint, of the reflected light ray. *A*'s time-scale is here coincident with the line *OA*. The distance between *OA* and *OB*, in a direction normal to *OA*, is then proportional to *A*'s measure of the space-interval separating *A* and *B*. This measure is given by the definition (iii) which assumes the equality of the out and return paths

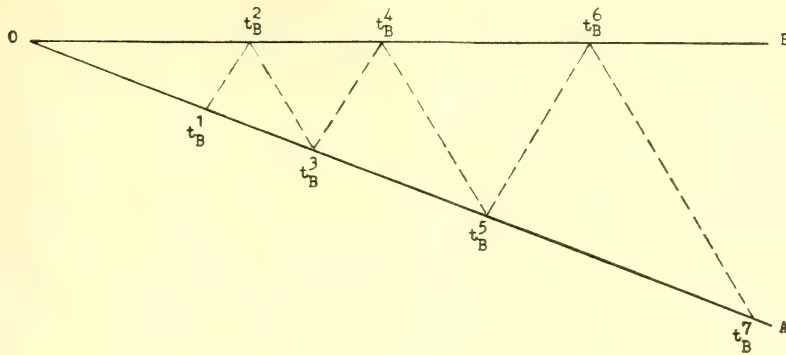


FIG. 3

Times of reflection, according to B 's intuitive standpoint, of the reflected light-ray. B 's time-scale is here coincident with the line OB . The distance between OB and OA , in a direction normal to OB , is then proportional to B 's measure, according to (iii), of the space interval separating A and B . The superscripts, 1 to 7, refer to the same seven events (of reflection) as timed by A according to Figure 2, and by B according to Figure 3

are irreconcilable even in terms of time dilatation and space contraction, yet stemming from the same assumption (the identity of t_A^m and t_A^n) as do the latter concepts. The intuitive approach further requires a different law of light propagation for the out and return paths, it implies that the propagation be considered relative to the source, S , on its outward path, but relative to the destination, D , on its return journey.

This contradiction is avoided by the rigorous application of the principle of relativity in the form of III, and it leads to a single law of light propagation for all paths and for the inertial systems of both S and D . In fact the same law then applies for all inertial systems since this law (e.g. in the form (17) and (18) in paper B) leads to the Lorentz transformation, and is in turn Lorentz-invariant.

The inequality of the out and return paths might be decisively tested by reflecting a light-beam on a body moving across the direction of incidence. If our approach is correct, the directions of the out and return paths will then differ, the angle depending on the relative velocity of the reflecting body. The astronomical phenomenon of aberration suggests that such a test may well bear out our contentions.

Should this test prove negative, or alternatively, if time dilatation or some comparable absolute effect is indeed shown to be a conse-

quence of uniform motion, then our concepts of relativity will have to be revised. Meanwhile we have attempted to show that these concepts form the basis of a system which is mathematically self-consistent and free of physical contradictions.

Acknowledgements

The author is indebted to Professor J. Blatt for directing attention to the implications of the intuitive approach as expressed by Figures 2 and 3. The mention of Synge's work is due to a suggestion by Dr. N. W. Taylor.

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Reflection of Plane Waves by Random Cylindrical Surfaces

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ABSTRACT—For an aperiodic cylindrical metallic surface illuminated by horizontally polarized radiation, the reflected field is established as a superposition integral and the reflection function is obtained as an integral representation, whose integrand contains surface dependent functions. Proceeding to the optics limit, the reflection function is found proportional to the Fourier transform of $\exp [Qz]$, where Q depends on grazing angle and wavelength and z is the surface height. Allowing a stationary stochastic process for the surface, the reflection coefficient, on the average, agrees with all previously derived results and the received intensity shows a dependence on the auto-correlation, $\rho(\eta)$, of the surface.

Introduction

Lord Rayleigh (1878), in his studies of acoustic reflections, approximated the solution to the problem of reflection of plane waves by cylindrical surfaces. This approximation was successively improved through the work of C. T. Tai (1948) and W. C. Meecham (1952). The approximation, in all cases, is a consequence of the infinite system of linear equations defining the solution.

About the time of Meecham's work (1952), interest in the reflection of waves was shown by M. A. Isakovich (1952). Here, the general problem of rough surface reflection was approached in the Green's function manner and solved in Kirchhoff approximation; Gaussian statistics for the surface height and auto-correlation were assumed. W. S. Ament (1953), interested in evolving a theory of sea clutter, also used a Green's function approach but solved the attendant integral equation using a variational procedure. Gaussian statistics were assumed, too, and the reflection coefficient derived was in agreement with the result of MacFarlane (1945) and C. L. Pekeris (W.W. II). Working from a different direction, using the field equivalence theorem approach and assuming, in approximation, the surface current densities, W. Magnus (1953), J. Feinstein (1954), and L. M. Spetner (1958) have derived asymptotic reflection coefficients; here, too, the free use of Gaussian statistics for the surface was made. As in the earlier treatments of the problem, the approximate specular reflection coefficient was obtained, one which showed a Gaussian dependence due to the assumed stochastic process.

This paper will deal with the reflection problem for an aperiodic surface. A plane wave polarized colinearly with the generators of the surface is reflected with a reflection coefficient dependent on the surface current distribution. The dependency is established from the appropriate Fredholm integral equation with a non-symmetric kernel describing the boundary-value problem of the first kind. The integral equation is solved in optical approximation and free use of Gaussian statistics is made in order that the determination of the average reflection coefficient, the average received power, for a unit intensity source, and the ratio of lobe maxima to minima as a function of the auto-correlation of the surface may be obtained.

Part I

A plane wave $\varphi_i(\vec{r})$, of direction cosines β, γ , polarized in the x -direction impinges on an aperiodic surface $S(y)$ which possesses single-valued properties. The scattered field, or more properly called the reflected field for small surface perturbations when specular reflection is dominant, caused by, equivalently speaking, surface current densities may be described by

$$\varphi_s(\vec{r}) = \frac{i}{4} \int_{\Sigma} H_0^{(1)}[k|\vec{r}-\vec{q}|] f(\vec{q}) ds \quad \dots\dots\dots (1)$$

where $f(\vec{q})$ is the surface-current density and the Hankel function is the appropriate Green's function. As $f(\vec{q})$ is unknown, one might just as well represent the reflected wave as

$$\varphi_s(\vec{r}) = \frac{i}{4} \int_{-\infty}^{\infty} H_0^{(1)}[k\sqrt{(y-y')^2 + \{z-S(y')\}^2}] \psi(y') dy' \quad \dots\dots\dots (2)$$

where $\psi(y')$ is now the unknown function and transformationally related to $f(\vec{q})$. By inserting the Fourier integral representation for the Hankel function, $\varphi_s(\vec{r})$ becomes

$$\varphi_s(\vec{r}) = \frac{i}{2} \int_{-\infty}^{\infty} \int_C \frac{e^{i\omega(y-y') + i\{z-S(y')\}\sqrt{k^2-\omega^2}}}{\sqrt{k^2-\omega^2}} \psi(y') dy' \quad \dots\dots\dots (3)$$

which can be written as

$$\varphi_s = \int_{C_1} R_1(\omega) e^{i\omega y + iz\sqrt{k^2-\omega^2}} d\omega \quad \dots\dots\dots (4)$$

with

$$R_1(\omega) = \frac{i}{2} \int_{-\infty}^{\infty} \frac{e^{-i\omega y' - iS(y')\sqrt{k^2-\omega^2}}}{\sqrt{k^2-\omega^2}} \psi(y') dy' \quad \dots\dots\dots (5)$$

at all points for which $z \geq S(y')$, i.e. at all points above the surface. Replacing $\psi(y')$ and $e^{-iS(y')\sqrt{k^2-\omega^2}}$ by their Fourier integral representations defined as

$$\begin{aligned} \psi(y') &= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \psi(\sigma) e^{iy'\sigma} d\sigma \\ e^{iS(y')\sqrt{k^2-\omega^2}} &= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} F[\sqrt{k^2-\omega^2}; p] e^{iy'p} dp \end{aligned}$$

and using the fact that

$$\int_{-\infty}^{\infty} e^{ixy} dy = 2\pi \delta(x)$$

where $\delta(x)$ is the Dirac delta function, equation (5) becomes

$$R_1(\omega) = \frac{i}{2} \int_{-\infty}^{\infty} \frac{\psi(\sigma) F[-\sqrt{k^2-\omega^2}; \omega-\sigma]}{\sqrt{k^2-\omega^2}} d\sigma \quad \dots\dots\dots (6)$$

so that the total field is

$$\varphi(\vec{r}) = \varphi_i(\vec{r}) + \int_C R_1(\omega) e^{i\omega y + iz\sqrt{k^2-\omega^2}} d\omega. \quad \dots\dots\dots (7)$$

Linearly transforming the variable ω to $\omega + k\beta$, defining the reflection function $R(\omega) \equiv R_1(\omega + k\beta)$, and imposing the boundary condition $\varphi(\vec{r}) = 0$ when $z = S(y)$, the integral equation for the field is

$$-e^{ik\gamma S(y)} \int_C R(\omega) e^{i\omega y + i\Gamma(\omega)S(y)} d\omega \quad \dots\dots\dots (8)$$

after $e^{ik\beta y}$ has been divided out. Fourier transforming the left-hand side of Eq. (8) and collecting terms under one integral, one finds

$$\int_C \left[R(\omega) e^{i\Gamma(\omega)S(y)} + \frac{F(k\gamma; \omega)}{\sqrt{2\pi}} \right] e^{i\omega y} d\omega = 0. \quad \dots\dots\dots (9)$$

Were one to solve this equation for $R(\omega)$, the intensity of radiation $I \equiv |\varphi(\vec{r})|^2$ could be readily found. As approximate solutions are helpful, a variational procedure to give the least-square fit to a true $I(\vec{r})$ when carried to completion yields an integral equation holding not only in the upper half-space but also on the surface *exactly* equal to Eq. (9). A sufficient solution to Eq. (9), and justifiable in a zero-order sense of Lord Rayleigh for high-frequencies, is

$$R(\omega) \cong \frac{-1}{\sqrt{2\pi}} F(2k\gamma; \omega) \quad \dots\dots\dots (10)$$

whereupon the total field is

$$\varphi(\vec{r}) \cong e^{ik(\beta y + \gamma z)} + \frac{1}{\sqrt{2\pi}} \int_C F(2k\gamma; \omega) e^{i(\omega + k\beta)y + i\Gamma(\omega)z} d\omega \quad (11)$$

with $\Gamma(\omega) = -\sqrt{k^2 - (\omega + k\beta)^2}$.

Part II

The surface is now considered to move randomly in time at a rate very slow compared to the emission frequency. In the case where the "periodicity" of wave motion is long compared to the length of time necessary to establish a steady-state, this neglects Doppler effects, the ensemble average reflected wave function is

$$\begin{aligned} \langle \varphi_s(\vec{r}) \rangle &= -\frac{1}{2\pi} \int_C \langle F(2k\gamma; \omega) \rangle e^{ik\beta y + i\Gamma(\omega)z + iy\omega} d\omega \\ &= -\frac{1}{2\pi} \int_C \int_{-\infty}^{\infty} \langle e^{i2k\gamma S(y') - i\omega y'} \rangle e^{ik\beta y + i\Gamma(\omega)z + iy\omega} d\omega dy' \quad (12) \end{aligned}$$

For a stationary stochastic process, one invariant with respect to y' ,

$$\langle \varphi_s(\vec{r}) \rangle = -\frac{1}{2\pi} \int_C \int_{-\infty}^{\infty} \Phi(2k\gamma) e^{-i\omega y' + ik\beta y + i\Gamma(\omega)z + iy\omega} d\omega dy' \quad (13)$$

where $\Phi(2k\gamma)$ is the characteristic function of the surface. Carrying out the integrations with respect to y' and ω , using a singularity function, one finds the average reflected radiation to be

$$\langle \varphi_s(\vec{r}) \rangle = -\Phi(2k\gamma) e^{ik\beta y - ik\gamma z} \quad (14)$$

so that the total radiated field is

$$\langle \varphi(\vec{r}) \rangle = e^{ik\beta y + ik\gamma z} - \Phi(2k\gamma) e^{ik\beta y - ik\gamma z} \quad (15)$$

For a Gaussian distributed surface, with variance σ^2 , the total field on the average is

$$\langle \varphi(\vec{r}) \rangle = e^{ik\beta y + ik\gamma z} - e^{-2k^2\gamma^2\sigma^2} e^{ik\beta y - ik\gamma z} \quad (16)$$

in agreement with previously derived results, MacFarlane (1945). The specular reflection coefficient is seen to be

$$R = -e^{-2k^2\gamma^2\sigma^2} \quad (17)$$

To find the total intensity, or power, of the received field, an ensemble average of $|\varphi(\vec{r})|^2$ can be found. But,

$$\begin{aligned} \langle |\varphi(\vec{r})|^2 \rangle &= \langle |\varphi_i(\vec{r})|^2 \rangle + 2\langle \text{Re} \{ \varphi_i^* \varphi_s \} \rangle + \langle |\varphi_s|^2 \rangle \\ &= 1 - 2\Phi(2k\gamma) \cos(2k\gamma\eta) + \langle |\varphi_s|^2 \rangle \quad (18) \end{aligned}$$

so attention is now directed to finding $\langle |\varphi_s|^2 \rangle$. As

$$|\varphi_s(\vec{r})|^2 = \frac{1}{2\pi} \iint F(2k\gamma; p) F^*(2k\gamma; \sigma) e^{ik\beta y + i\Gamma(p)z + iy p - ik\beta y - i\Gamma^*(\sigma)z - iy\sigma} dp d\sigma$$

ensemble averaging produces

$$\langle |\varphi_s|^2 \rangle = \iiint \langle e^{i2k\gamma S(u) - i2k\gamma S(v)} \rangle e^{i\Gamma(p)z + iy p - i\Gamma^*(\sigma)z - iy\sigma - ipu + i\sigma v} dp d\sigma dudv \quad (19)$$

it follows that

$$\langle |\varphi|^2 \rangle = 1 - 2\Phi(2k\gamma) \cos 2k\gamma z + \Phi[2k\gamma, -2k\gamma; \eta] \quad (20)$$

since

$$\begin{aligned} \langle e^{i2k\gamma S(u) - i2k\gamma S(v)} \rangle &= \iint e^{i2k\gamma z_1 - i2k\gamma z_2} W_2(z_1, z_2; \eta) dz_1 dz_2 \\ &= \bar{\Phi}[2k\gamma, -2k\gamma; \eta] \quad (21) \end{aligned}$$

and the four-fold integration produces unity. η is the correlation time, $t_1 - t_2$, corresponding to z_1 at t_1 and z_2 at t_2 . The first term of Eq. (21) represents the auto-correlation of the incident field, which must be unity, the second term the cross-correlation of the incident and reflected fields, and the third term the auto-correlation function for the reflected field. For a Gaussian distributed surface, the joint characteristic function $\Phi(2k\gamma, -2k\gamma; \eta)$ is

$$\Phi(2k\gamma, -2k\gamma; \eta) = e^{-4k^2\gamma^2\sigma^2\{1 - \rho(\eta)\}} \quad (22)$$

where $\rho(\eta)$ is the auto-correlation function of the surface. The total field may thus be expressed as

$$\langle |\varphi|^2 \rangle = 1 - 2e^{-2k^2\gamma^2\sigma^2} \cos(2k\gamma z) + e^{-4k^2\gamma^2\sigma^2\{1-\rho(\eta)\}} \quad \dots\dots\dots (23)$$

The ratio of maximum to minimum intensity in the lobe structure, expressed in decibels, is easily seen to be

$$W(DB) = 10 \log_{10} \left[\frac{1 + 2e^{-2k^2\gamma^2\sigma^2} + e^{-4k^2\gamma^2\sigma^2\{1-\rho(\eta)\}}}{1 - 2e^{-2k^2\gamma^2\sigma^2} + e^{-4k^2\gamma^2\sigma^2\{1-\rho(\eta)\}}} \right] \quad \dots\dots\dots (24)$$

Special cases, for $\rho(\eta)=0$ and $\rho(\eta)=1$ are

$$W(DB) = 20 \log_{10} \left[\frac{1 + e^{-2k^2\gamma^2\sigma^2}}{1 - e^{-2k^2\gamma^2\sigma^2}} \right], \quad \rho(\eta)=0$$

$$W(DB) = 10 \log_{10} \left[\frac{1 + e^{-2k^2\gamma^2\sigma^2}}{1 - e^{-2k^2\gamma^2\sigma^2}} \right], \quad \rho(\eta)=1$$

$$W(DB) = 20 \log_{10} \left[\frac{1 + D(\gamma)e^{-2k^2\gamma^2\sigma^2}}{1 - D(\gamma)e^{-2k^2\gamma^2\sigma^2}} \right], \quad \rho(\eta)=0$$

(Spherical Earth Case) . . (25)

Among the special cases has been added a relation apropos to the spherical earth problem. In this event, the only modification, for engineering calculations, is the inclusion of a divergent coefficient which is also incident angle sensitive. Numerical studies made at the Naval Research Laboratory in the U.S.A. prior to 1956 in connection with airborne early warning radars showed the deterioration of W , i.e. $W \rightarrow 0$, at high grazing angles and practical independence of surface roughness at low grazing angles for wavelengths less than 1 metre and surface undulations of order of 3 metres.

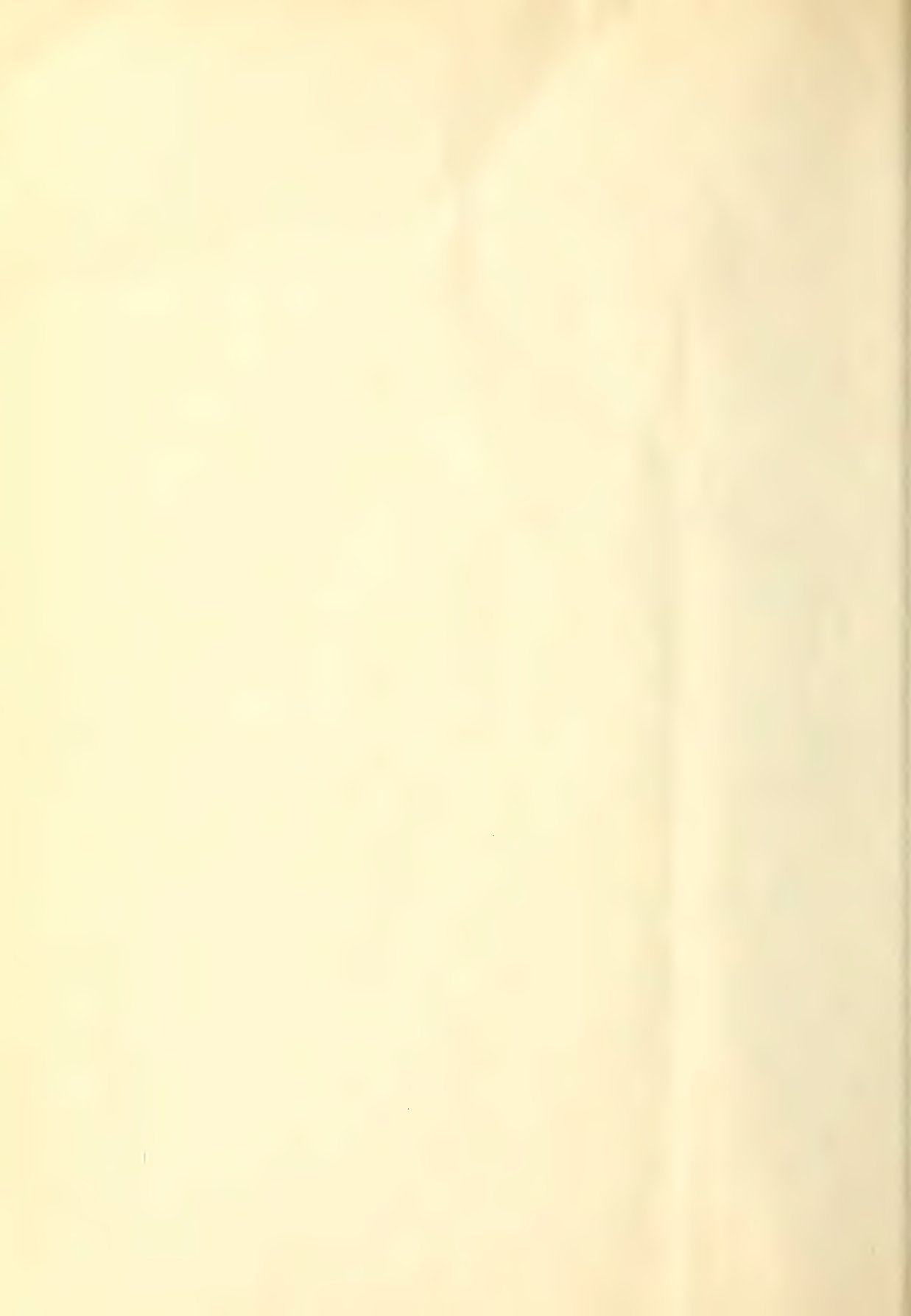
Summary

The boundary-value problem of the first kind has been solved for the plane-wave case incident on an aperiodic cylindrical surface. Polarized tangentially to the surface generator, the reflected radiation has been established as an integral representation, whose integrand contains transformations of a function $\exp [Qz]$, where z is the surface height, and which has been approximated in the optics limit. Invoking stationary stochastic properties to the surface, the specular reflection coefficient, the total received intensity of radiation, and the ratio of maxima to minima in the lobe structure have been found as functions of the characteristic functions of the surface.

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Chemistry and the Mining Industry*

H. A. J. DONEGAN

I am fully aware that courtesy and precedent will call for publication of this address in our journal which, having world distribution, gives these words a chance of being permanently available. Therefore it is quite possible that curiosity may lead someone, maybe a future President, to look over past addresses long after I've shuffled off this mortal coil, and he, from his vantage point of later knowledge, may find them quaintly amusing.

Fifty years hence our present techniques, professional and political, may, unless a world disaster overtakes us because man is becoming so clever, be as outmoded as those of fifty years ago appear to us today.

I have forty-one working years to look back over and as, apart from journeys overseas and to other Australian States, thirty-seven have been spent in the Chemical Laboratory of the Mines Department of New South Wales, it is only natural that I should select Chemistry and the Mining Industry as the general subject, and should draw on the development of that laboratory and the service it performs in the mining industry for the particular substance of my Presidential address.

The Mutual Challenge of Chemistry and Mining

Those of us whose memory extends beyond 50 years believe that this is the most remarkable age in mankind. Perhaps it is, even more so than the period of the Renaissance, because within our living memory, knowledge and its application have extended man's horizon in every direction of human endeavour to distances we ourselves, when younger, believed beyond the bounds of possibility or of which we just had no conception.

The great primary industries of mining and agriculture are alike in their need of the chemist, but they have one great difference. The farmer can sow, and reap a large harvest for mankind from a small fraction of his previous crop, but

no small portion of a mineral lode, once recovered from the earth to serve man, can be sown to reproduce another lode of that mineral. Our mineral wealth in any particular item is a wasting asset. It is part of the world's limited capital which is being withdrawn in rapid and ever increasing amounts. In any economy and under any set of conditions, mineral resources are of critical importance. It behoves us, and the legislatures of our country, therefore always to see that each withdrawal is as complete in itself, that our recovery of the mineral from each deposit or ore body is as complete as possible and that when recovered it is processed and used to the best advantage in the broad interests of national and international welfare.

Mining, basic to all other industry and one of the most ancient professions, has always been essentially allied with chemistry because, generally speaking, without the application of chemistry neither can the value of minerals be assessed nor can their valuable constituents be separated from the matrix in which they are found. As Longfellow said when speaking of man and woman, they are "useless each without the other". In fact the development of the mining industry, and of chemistry, is very closely bound up with the development of our modern civilization which depends on them for its very existence.

Wherever the mining industry goes it has always had a profound effect on society. Our own country's history, as well as that of many another nation, attests this fact. When a new country is opened up by mining, as was Australia, or a new mining field in a country is discovered, its isolation ceases. Population rapidly increases, and other industries tend to grow up around the mines. No town booms so quickly as a mining town, or is so attractive to the adventurous, the impulsive, and the selfish, and great responsibility lies on the mining engineers and scientists who should plan development to accord with what is best, not only for their particular company shareholders and the mining industry, but for society generally, and the national welfare, present and

* Presidential Address delivered before the Royal Society of New South Wales, April 5, 1961.

future. This is especially so in the prospecting exploration and development of what we are pleased to call backward or primitive countries.

Mining engineers and scientists must be men of many parts, and no means have been found so effectual in promoting the arts and sciences connected with the economic production of the useful minerals and metals, and the welfare of those employed in these industries, as the free interchange of experience among those actually engaged in mining and metallurgy. In this connection it has been my fortune to experience, over a number of years, the camaraderie which exists among mining engineers, chemists, metallurgists and geologists all over the world and at the annual general meetings of our own Australasian Institute of Mining and Metallurgy, of which some of our Society are members, and at the quaternary Commonwealth Mining and Metallurgy Congresses, held in different Commonwealth countries in turn, the delegates obtain tremendous mutual assistance and thus boost progress in their respective professions and the mining industry generally.

It has been a characteristic of mining since the turn of the century that, in accord with world demand, steeply rising production has necessitated the working of progressively lower grade ores, and consequently higher tonnages. In their efforts to counter the effect of the depletion of mineral resources, the higher efficiency of the chemist and metallurgist in pushing back the limits of payability is continually increasing the reserves in sight, but there are ultimate limits beyond which they cannot go.

One has also to realize that in the face of shortage or high price of particular metals the consumer will increasingly turn to substitute metals and alloys, or even to non-metallic substances such as synthetics, where such can be used. Some substitutes have been found better than the original metals for special purposes. Thus aluminium and its alloys have made inroads into the steel and copper markets, and magnesium in its turn is in some cases displacing aluminium, while synthetics affect any markets where properties such as ease of formability, colour, lightness, and reliability of design are important.

This permits great flexibility in consumer requirements and although the chemist is, in the main, responsible for this state of affairs, he also assists the mining men to meet the very challenges he creates. It is perhaps a comfort to the mining man to know that each metal possesses its own unique properties which give

it particular uses in fields the substitutes cannot enter, and that world consumption of metals, because of these particular properties, is increasing in line with the growth of world population and the upward trend in living standards in all countries.

Development and Progress

Since the mists of antiquity chemistry has, through ceaseless experimentation, developed to the stage when today the chemistry departments of the universities, large industries, and progressive governments with applied research staffs on various chemical projects, all seeking new and useful knowledge, flood the world with increasing thousands of published papers. This is demonstrated in the rapid year by year expansion of the abstract services of scientific societies and professional institutes, and is exemplified particularly in the case of the "Chemical Abstracts" of the American Chemical Society, which now abstracts approximately 72,000 papers per year from 575 journals, and has now felt compelled to commence a special publication twice a month, of 3000 indexed "Chemical Titles" only, to enable leaders in chemical research and teaching to keep pace with the literature available.

The National Science Foundation estimates that U.S.A. alone will spend about one thousand million dollars on basic research this year (the biggest single item being salaries).

Chemistry itself has thus grown into a vast tree of knowledge so greatly beyond the capacity of any one person, however devoted to its study, that he is perforce compelled first to confine his activities to one of its great branches, organic, inorganic, or physical, and then to move out along one of the sub-branches, and finally even to the twigs and leaves, where he almost loses sight of other chemists on different branches. Sometimes he cannot even intelligently follow a fellow chemist's conversation, let alone his written word.

Specialization however, though unavoidable, should be a chemist's particular and not his sole usefulness. The scientific discipline, of which a recognized university degree or equivalent qualification is the hallmark, is a first essential; the next is at least one other interest not directly related to chemistry to widen the basis of judgment, assist in understanding human nature, and the art of getting on with people, for when all is said and done we live in a world of people.

Many chemists, in Australia and elsewhere, have attained senior executive rank in the

mining industry where their ability to appreciate technical considerations is specially needed, as well as the other abilities which form no part of a science or technology degree. One has only to consider the lists of past Presidents of the world's mining and metallurgical institutes, and to note some of the distinguished members of those bodies, to recognize this fact.

In the demands of the world for new needs, and the challenge for new means to meet them, chemists are indispensable. On the road of progress you will always find the chemist travelling in harmony with men of other disciplines: engineers, physicists, geologists, medical men and, in fact, men of all professions.

The chemist is able to assist in solving the problems of the mining industry, and his own problems, because he has inherited a handsome legacy of accumulated wisdom and knowledge, to which legacy he in his turn may contribute something for the benefit of those who follow him.

His work nowadays is of necessity both of research and of what is termed routine nature, for the essential analytical control (a very important function in industry carried out often by staff in training, using methods standardized either by an outside authority such as a Standards Association on the advice of experts, or by modifications adapted to suit the particular industrial requirements) varies itself in nature as do with time the very methods used themselves. Rigid adherence to standard methods to obtain comparable results between laboratories is often necessary, but does constitute a danger to progress which must be carefully watched.

Any industrial or government laboratory must be continually carrying out a certain amount of research in order to develop its service to its company, the public, or the State. In the mining industry the ultimate objective is production via development, and chemical research is carried out, partly to improve existing extractions, processes or products, to develop new processes for the same product, or new products for the same use or new uses. Research and development are usually conducted by chemists and their assistants working in teams, progressing from assistants through research officers to a general director of research. Research is not all glamour. It is not without its periods of frustration and despair, and the conclusions are more often the results of patient careful sustained effort, rather than brilliant inspiration, but it can be exciting and satisfying. Research is not a magic process which will

guarantee immediate returns, nor a luxury to be indulged in only when times are good.

Tedious, empirical, gravimetric analysis requiring painstaking care and long experience to reduce doubts as to accuracy still has its place, particularly in classical rock analysis, but nowadays there are so many ways of measuring quantities without weighing them, especially very small quantities, that there is usually some easier method of determination.

The useful properties of many of the reagents now used seem to have been discovered by accident and their use developed by the analyst. Schwarzenbach did not have the analyst in mind when he began his classical investigations on ethylene diamine tetra acetic acid (the E.D.T.A. now so extensively used in analysis); also copper, aluminium, and beryllium can now be determined by use of a drug originally used as a disinfectant of the intestinal tract (8-hydroxy quinoline potassium sulphate) (Wilson, 1960).

It is said that anyone can do chemical determinations if an analyst tells him how to do the separations. Certainly many large industrial laboratories employ relatively unskilled labour on routine determinations, sometimes using very expensive and complicated apparatus, thus offsetting the low cost of the operative against the high cost of the equipment. The apparatus used, however, was originally evolved and calibrated by chemists for their needs and, in the event of trouble, the unskilled operator could neither diagnose nor correct the trouble, nor in emergency use an alternative method. On the Rand goldfields of South Africa I saw young ladies with no academic qualifications operating spectrophotometers and spectrographs costing many thousands of pounds each, but in the background, and of course responsible for their work, were well qualified analysts.

Chemical analysis, in short, is a body of techniques, chemical and physical, used to ascertain the chemical composition of substances. It is an economic activity where theory often follows practice. In universities, chemical elements and compounds are studied for their intrinsic interest and some may be shown to have properties which might be of value to the analyst. The analyst is only interested in them if they can produce quicker, easier, cheaper, or more accurate analyses. The most expensive component of an analytical report being laboratory time, the wise analyst continually strives to supply the information required of him as fast as he can without loss of accuracy, and the wise mining executive,

generally realizing that chemical information and control is not an overhead but part of the production costs, and essential to control the quality and quantity of his product, will assist him in that endeavour.

Modern analysis entails the use of what may at first sight appear very expensive equipment and reagents of a wide variety of types, and involves, as before stated, a knowledge of other disciplines than chemistry, as it is commonly accepted, to understand and perform the techniques required in carrying it out.

The Chemical Laboratory of the Mines Department

When I first commenced duty in the Chemical Laboratory of the New South Wales Mines Department it already had a very high reputation for precious and base metal assaying, and a world reputation for classical high quality rock analysis. Some work had been carried out on coal and a few gas analyses made, the first in 1910. The equipment, techniques used, and the academic standing of the staff were in keeping with the general standards of 40 years ago. My predecessor and I were both told by our then chief that we were wasting our time learning physical chemistry. Careful attention to, and the following of, old and tried methods were considered more important than such frippery. Discipline was stern and initiative repressed. However, the quality of the work produced, through insistence on care and accuracy, was remarkably high compared with that attainable under modern conditions.

"In carrying out chemical analyses nowadays we are half the time not primarily concerned with chemical analysis but with physics, but we are not analytical physicists, but analytical chemists because what we are interested in is not usually the physical state of our samples but the chemical composition, and we use any criterion, chemical, physical, etc., that will help us to obtain the desired information." (Wilson, 1960.) There are of course times when the physical state of some of the samples submitted and the physical properties we determine are most important, as in our ceramics section, but even there the physical properties are allied with the chemical composition.

In our laboratory I have seen the slow and stately long beam chemical balances give way to the short beam, thence in turn to the Vernier scale, the chainomatic, the dampened aperiodic, and finally to the constant load single pan (Mettler) type to make weighing simpler, quicker and more accurate.

I knew the time when almost every analytical and assay determination was carried out gravimetrically, e.g., copper and antimony as "sub-sulphides", change over the years to volumetric analysis using progressively indicators, external and internal, to electrically recorded methods of indicating the end point; spectrophotometry replacing Nessler tubes for colour comparisons and determining alkali metals in solution; recording flame spectrophotometry determining accurately and quickly Caesium and Rubidium, etc.; rapid polarographic determinations of metals in the one solution which we once found difficulty in determining separately; fluorimetry determining small concentrations of Uranium; gas chromatography determining quantitatively gases, once completely beyond the capacity of old equipment even to identify, in attenuated concentrations that our old analysts would have believed indeterminable; X-ray diffraction and X-ray spectrographic methods used for identification of minerals and quantitative analysis of their components; and the use of complexometric titrations with chelating reagents in ordinary assays and analytical work, and so on.

I have already mentioned the scope of the work carried out by the Chemical Laboratory 40 years ago. This work was carried out in three laboratory rooms: special, inorganic, and fire assaying. No charge was made for work carried out as the greater bulk was for prospectors—some little offset to the hard life of the unpaid original seekers and discoverers of our mineral fields. The special work was almost entirely for our geological surveyors and the staff of the geology school of the University. The library was pitifully inadequate, and the annual vote for all equipment, chemicals, and stores was £300 p.a. Three only of the staff, two of them the most junior, were academically qualified, but the seniors were of sufficient practical experience to be accepted in Chemical Societies and to gain world reputation as A.1-grade rock analysts.

Today we are staffed with double the number of professional men, all of whom are well qualified academically, plus nine University trainees and a corresponding competent general division staff to handle the extensive variety of equipment, reagents, and clerical duties as well as sample preparation, cleaning, and attendant duties. Our annual vote for minor equipment exceeds £1200, plus a multiple of that for major equipment. Laboratory space has been considerably extended and sub-

divided, and our library brought and kept up to date. We charge private organizations for work which they find unable to get done elsewhere, while still preserving the policy of no charge for prospectors, or for work of national and scientific value. Naturally, the laboratory is registered with the National Association of Testing Authorities. Salaries are now adjusted to a career scale in common with other disciplines in government service today.

The present organization comprises a Chief, a Deputy and then Senior Analysts in charge of the following sections: Precious Metals, General Inorganic, Rock Analysis, Fuel, Ceramics, Gas Analysis, Safety in Mines, Geochemical Prospecting and Waters, Special Instrumentation, and Explosives, Inflammable Liquids and Dangerous Goods. The last-named was added when the Explosives Department Laboratory was amalgamated with the Mines Department in 1922. Each section head is a recognized expert in his particular field, his advice is sought by other Government bodies and the public, and where required he serves on appropriate State committees, Standards Association of Australia committees, gives lectures and acts as expert witness in court. Some remarks concerning the work of each section and its *raison d'être* may be of interest.

Precious Metals (Fire Assaying)

In the Precious Metals section we find the methods and equipment used by the ancient chemists allied with modern equipment and techniques.

Gold, one of the very few metals found in its natural state, was first used for adornment and ornament because of its many noble properties, relative scarcity, and lasting beauty, but soon developed a parallel function which surpassed its first use—as a means of value, a store of wealth, and a medium of exchange. Sir Charles Morgan Webb states: "No modern monetary invention can provide for the countless millions of mankind that feeling of confidence in the future which has been attached to gold by the experience and tradition of 50 centuries" (Webb, 1960). It gives stability to the world's economy and is the foundation of orderly trade between nations.

The search for gold led to great discoveries in the old and new worlds, agricultural and industrial development following in their wake. Its indestructibility is evidenced by the survival of gold articles after being buried 5000 years under conditions which caused the corrosion and even disappearance of silver and other

metals. It was originally won, as in Australia, from alluvial deposits, but in ancient Egypt gold was won by firesetting rock. Gold coins were used in Ephesus in 800 B.C. Australia has produced a large quantity of gold, including the largest alluvial nuggets and the largest single mass of gold ever found (Holtermann and Byers' at Hill End, N.S.W.), but in 1959 produced only one million ounces compared with South Africa's 20 million, and is now fourth largest producer.

Silver is commonly regarded in terms of its intrinsic worth as coinage, jewelry and silverware, whereas industrial usage accounts for well over half the silver consumed in the free world each year (296 million ounces in 1959). It has the highest electrical and thermal conductivity and the highest optical reflectivity of all metals and only gold is more malleable and ductile. The main industrial use for silver and its salts is in the photographic field, but it is also used in air conditioning, automotive and electronic industries, in aircraft, missiles, and rockets, alloys, solders, and brazes, in radar, and for bactericidal purposes.

The craft of the assayer evolved from necessity and has been practised since antiquity, the purity of gold and silver being expressed by weight relations as long ago as 2000 B.C. There are biblical references to the loss in weight of impure gold in the furnace. Fire assaying remained the basis of assaying, even for other than precious metals, for many centuries and it has a longer continuous history than any other quantitative chemical process. Being indispensable to a trial of coinage, accuracy was essential. Cupellation was used for the assay of silver collected as tax in the 12th century. We read that blank determinations were made on the lead used to obviate errors, and direction given as to care of balances and to use of *aqua fortis* used to "part" gold from silver in the 14th century.

The traditional methods of previous centuries were revealed to a wider public when printed books became available in the 16th century, an example being the work of Agricola in his volumes *De Re Metallica*, in which are diagrams and details of techniques of mining, metallurgical and assay operations still used today. In the larger mining centres of Central Europe assays were carried out at the rate of hundreds per week, and the assayer's work was recognized as an essential and natural part of the economic life of a community. In the 18th century assaying influenced, and was influenced by, the increasingly scientific nature of chemistry.

In technique, especially in the construction and use of the balance, assayers were often in advance of their contemporary chemists (Greenaway, 1960).

In our routine assays for gold and silver we still flux and fuse in coke-fired furnaces unaltered in design from antiquity (and in fact we still use the same counterweighted doors to the furnaces as were used when the departmental laboratory was set up 80 years ago). We still use the same types of crucibles, cupels, tongs, etc., as the ancient assayers and follow the same techniques. We still have the 17 lb. bucking hammer and the 30 in. square, 3 in. thick steel plate on which all the samples were crushed and ground by hand until 1930, a dusty method of sample preparation which cost the lives of two samplers through silicosis.

But we have progressed. We have purer chemicals, finer machine grinding of samples with suitable ventilation, regular atmospheric dust counts and medical examinations of the sample preparator to avoid danger of silicosis, better balances, and a better theoretical knowledge of the principles underlying fire assaying and produce results to a greater accuracy (5 grains per ton, or roughly 1 part in 3 million—better if required).

In addition to determinations of gold and silver, this section is responsible for assaying for platinoid metals, but fire assays for tin, lead, and copper have not been carried out for over thirty years.

Platinum and platinoid metals are used as catalysts in the oil, gas, and acid industries; in the glass and glass fibre industries; in electrical contacts; and, as is better known, in jewelry and laboratory equipment.

The section also carries out amalgamation and cyanidation tests to ascertain the amenability of ores, tailings, slimes, dumps, etc., to these processes and, in common with the general inorganic section, control work on relevant beneficiation experiments. It also recovers bullion from gold and silver wastes (gold leaf, etc.) from the Government Printer; and from solutions, and silver recovery units used in photographic developing baths of Government bodies and hospitals, and assays the bullion it produces for the Government Stores Department, which arranges their sale.

It is intended when time permits to investigate paper chromatographic methods so that prospectors can rapidly assess gold values, and consequently cover a greater area of country before returning to base with selected samples

for the assayer, because gold prospecting still remains the province of the fossicker on foot, ever trying, ever hoping to make a satisfactory "strike". There seems little doubt, however, that fire assaying, which has stood the test of time, will hold pride of place as the most reliable method of determining gold and silver values for many years to come.

General Inorganic Section

This section is responsible for the determinations of all other metals, including the glamour metals, type metals and alloys, lime-stones, magnesites, dolomites, gypsums, bauxites and miscellaneous inorganic work.

In contradistinction to the Fire Assay section the techniques used and the facilities available have changed completely.

The ventilation of our fume cupboards used to be by induced draught from the crushing room fan, and was very poor. There were doors to the fume cupboards, but it was little wonder that the staff were frequently very badly affected by acid fumes and sulphuretted hydrogen. Beach sands were tested for tin by reducing them in a gas heated hard glass tube with a stream of hydrogen generated in Kipp's apparatus. Acid ferric salts were also often reduced for titration by nascent hydrogen produced with metallic zinc. Molybdenum was precipitated as sulphide under pressure of sulphuretted hydrogen in bottles, securely stoppered, wrapped in cloths and placed in boiling water. We therefore had hydrogen explosions, or a molybdenum bottle exploding occasionally, to live-up things. We also had a couple of coal gas explosions as a result of which large, heavy porcelain sinks were flung about and heavy benches and everything in or on them wrecked. Common acids were used by the hundredweights per quarter. We had to test all reagents for purity and when necessary purify them ourselves.

Today our better ventilation permits us to have open fume cupboards; we have progressed to more elegant techniques, and our work is carried out more smoothly, efficiently and accurately, using the modern apparatus previously referred to. Moreover the work is of greater interest and variety.

Rock Analysis Section

Here the Laboratory reputation is as high as ever, by international test conducted by the Massachusetts Institute of Technology and the United States Geological Survey, and furthermore we have the advantage of better equipment,

better chemicals and later knowledge than were available to our old rock analysts. One man now turns out three times the work per annum that three men used to do and gives more precise results with a larger number of constituents. In this section, also, pure minerals are analysed, our result for Davidite, for instance, being internationally accepted as standard (Butler and Hall, 1960). Other work has included determinations of the fluorine content of fossil bones to assist estimation of their geological age.

Fuel Section

Here there has been great progress. The gas-heated, carbon and hydrogen combustion furnace of my youth has been replaced by the better controlled electric furnace. Volatile matters are not done, as then, in a platinum crucible first over a low gas flame and then blasted for two minutes with a foot-bellows operated blow pipe, but by standard technique in electric muffles. Ashes are done in batches in electric muffles, and moistures in electric ovens, or by distillation with toluene. Calorific value determinations by the Thompson's calorimeter were spectacular and used to be great fun, with sparks and bubbles shooting out under the water, and copious clouds of white smoke, and after the final reading of the thermometer had been made, 10% was added to the determined value for radiation losses. I have seen the progress from the old style enamel lined Mahler bomb calorimeter with lead washers to the latest stainless steel type with automatic tapping of the thermometer, reading by magnification and eye estimation to $1/1000^{\circ}\text{C.}$, and automatic time signals by light and buzzer. We can, with the Gray King apparatus, determine either the low temperature or high temperature carbonisation products of coal, such as coke or residual fuel, tars, liquors, ammonia, and gas in percentages by weight or yields per ton, with analyses, specific gravities and calorific values of the products to give thermal balance. We determine the different forms of sulphur in coal, ash fusion points, swelling index and agglutinating value. Specific gravity used to be determined on crushed coal of specific size, discarding fines and oversize; naturally it was not a representative value. That is no longer the case. The coal sections of scout bore cores are sampled and analysed ply by ply, and results calculated for composite samples with or without shale bands. Ash analyses are carried out. These are regular determinations so that our coal resources can

be used to best advantage. Similar analytical work on wood, sawdust, brown coals, black coals, cokes, and ashes is related to power house boiler efficiency tests, and such special investigational work as may be required. The Mines Department is shortly to undertake investigation of our Riverina brown coal deposits by scout boring, and subsequent analysis of the samples obtained.

The Fuel section also carries out all the usual tests on liquid fuels natural and manufactured, such as distillation range, specific gravity, sulphur, ash, calorific value, cloud and pour point, flash and fire point, etc.; and calorific value, specific gravity and composition of ordinary fuel gases.

The Ceramic Section

This analyses and carries out physical tests, plasticity, green strength, drying, shrinkage, and ascertains results of firing at specific temperatures on colour, shrinkage, porosity, hardness and fusibility; glazing, and viscosity of clay slips, etc., to determine the suitability of our clay and shale resources for the various ceramic purposes in the manufacture of brick, tile, pipe, and porcelain ware, and even uses in fullering or paper manufacture. Certain investigational work for the industry is performed.

Gas Analysis Section

This analyses, in modern precise apparatus, airs and atmospheres of all types for toxic, noxious and inflammable gases usually for mine safety purposes, such as investigations on coal mine fires, areas sealed due to fire, spontaneous combustion and the like. It has taken part in investigations of fatalities in pipes and sewers for the Water Board, occluded gases in coal seams for University research on underground gas outbursts, and even the gas from fermenting tobacco, and the batteries of submarines for the Royal Navy. It has investigated atmospheric pollution by metallurgical works for the Health Officers of the Sydney City Council, and the laboratory was represented on the State committee for Smoke Abatement. During the last three years a recording gas chromatograph, a technique which only originated in 1952, has been built and calibrated by the Senior Gas Analyst and is in regular use on natural gases determining quantitatively constituents, like the higher homologues of the paraffin series, that our older apparatus was incapable of detecting. The valuable gas helium has been detected in small quantities in some of our natural gases. A recording infra-red gas analyser

is being installed to supplement and extend the work of the Graham Lawrence carbon monoxide apparatus as well as determine other gases—truly a far cry from the Winkler burette with separate absorption and explosion pipettes (we had fun sometimes there, too) used in my early years, and the Haldane, and Bone and Wheeler apparatus which followed them. This section also tests various types of indicators, used in mining, for detecting toxic, noxious, and inflammable gases.

Safety in Mines Section

Apart from the gas analysis for toxic and inflammable gases previously mentioned, and the testing of explosives detailed later, this section is responsible for determining the composition of the exhaust gases, under varying conditions of speed and load, of the diesel locomotives used underground, their external temperatures, conditioner tank pollution, and the extent of pollution of mine airs from their use, to ascertain compliance with official requirements. These locomotives are of various types and sizes and are tested on the surface, sometimes in improvised galleries filled with explosive atmospheres, before they are permitted to be used underground. Ordinary petrol internal combustion engines are not permitted underground for a number of reasons, and evidence has been given in court of their exhaust gas composition, extent of contamination of mine air therefrom, and fire hazards from the fuel in a case of breach of regulations. This section is much concerned with dust, both as regards airborne concentrations of finer particles and their nature in the war against miners' lung diseases, and as regards the combustible volatile content of the ordinary visible coal and shale mine road dust, which has been responsible for the worst colliery explosion disasters, and also as regards the composition and physical state of the stone dusts which are used to prevent these explosions. Several hundred road dust samples are analysed annually. On the one hand the section works with the medical profession and the Occupational Health division of the Public Health Department and on the other with the Coalfields Branch, Mines Inspection Branch and the Joint Coal Board. The laboratory is currently working on shot firing fumes in both coal and metaliferous mining, using various portable indicating instruments and analysing samples for concentrations of noxious gases, such as the insidious oxide of nitrogen which can slay an apparently healthy man in his sleep several hours after

exposure. Free silica (quartz) determinations on rock strata and dusts are made to guide compliance with the new proclaimed airborne dust concentration standard, which varies with the percentage concentration of free silica (quartz) in the parent rock producing the dust. Supersonic sound method has been used, to free the minute quantity of ultra-fine dust from the filtering medium of airborne dust sampling instruments used during test on roof bolting operations, so that it could be analysed by X-ray methods. The Chief Inspector of Coal Mines calls for chemical technical assistance in investigations of the various types of fire, explosion, and gas outbursts which occasionally occur underground, the composition of plastic tubular bags to be used when filled with water for stemming in shot firing, and tests of other substances for fire proofing timber and brattice and rendering mine seals and brattice impervious, the use of reflecting tape, wetting and floor-consolidating agent, and various tests on self-contained breathing apparatus used in mine rescue work as regards composition of inspired and exhaled air breathed by the wearer and of the absorbents and oxygen used as to compliance with safety requirements. Flame safety lamps, the modern development of the Humphry Davy lamp and still the most reliable practical indicators of foul or inflammable atmospheres, have also been tested for safety in use. In fact this section advises the Chief Inspectors on all matters affecting mine safety where chemical knowledge is required. This entails a certain amount of up-to-date knowledge on operational mining here and overseas, and field knowledge of underground and mine rescue conditions, in order to understand the nature of the chemical work involved. This laboratory represents the Department on the State committee on Coal Mine Dust Research and Control and its technical sub-committees, and the industrial respiratory devices committee of the Standards Association of Australia.

Geochemical and Water Section

Here again a wide variety of work is undertaken. Metallometric surveying, or geochemical prospecting, by outcrop and drill hole sampling, is a primary reconnaissance tool, and no area of whatever topography, climate, or vegetation can be regarded as adequately mapped unless thus investigated. Samples of soil taken in a regular pattern over the area investigated are assayed for the required constituents (as yet usually only for the base metals, copper, lead and zinc), and the determinations in parts per

million plotted on geologic base maps and contoured to indicate the points where the mineral lode should be closest to the surface, with a rough outline of its shape, to make prospecting drilling less of hit-or-miss affairs. Since the analyst is looking for such small concentrations, ordinary distilled water, which contains traces of the elements from the metal still or glass water containers and would give positive readings with the spectrophotometer, is useless and we have to use water which has passed through resin ion exchange columns, to remove bases and acid radicles, and has been caught and stored in polythene bottles. An electric recorder indicates when the columns need regenerating or changing. This treated water has displaced ordinary distilled water, which in my early days was tested only for chloride content and was stored in glass bottles, for all our normal analytical work.

This section also carried out density, conductometric, and salinity determinations on several hundreds of sea water samples for the Navy, in connection with isopycnic oceanography during the International Geophysical Year, by electronic means in a constant temperature water bath. It analyses waters for all uses, other than for potability, with a combination of electro-conductometric and chemical methods. It assists the Geological Survey in surface and underground hydrology by analysing well, bore and surface samples so that the courses of underground aquifers and stream junctions can be traced and optimum sites selected for new wells or bores.

It also carries out analyses of river and dam waters to determine the extent of pollution or poisoning by mining operations, and advises as to possibility of remedial measures. In this connection the Senior Analyst has served on a combined Commonwealth and State committee set up to investigate the pollution of the Molonglo River flowing through the Federal Capital Territory. He is a recognized authority on geochemical prospecting, complexometric titrations and is developing the X-ray section. He has just determined the sulphide content of the sea water at Circular Quay which will be used in the air-conditioning plant in our tallest (A.M.P.) building.

The Explosives, Inflammable Liquids and Dangerous Goods Section

Here samples of all commercial explosives, including detonators, fuses, fireworks and sporting ammunition, are tested and recommended as to safety for issue and use, and

technical advice is given on handling, packing, storage and transport.

Inflammable liquids are tested and classified according to the regulations and technical advice given on all matters of storage including construction and layout of inflammable liquid tank farms, ship to shore installations, and the necessary foam etc. fire-fighting equipment which is also inspected and tested for efficiency; the construction of mobile tanks for delivery depot to service station, and the construction and layout of the retailers' underground tanks and delivery pumps, nozzles, and hoses. Flame proofing of motors in hazardous atmospheres, other than mines, to avoid fire and explosive risks also comes under this section. Motion picture film vaults and film processing plants, acetylene cylinders etc., are dangerous goods matters and the construction etc. is carefully vetted to see that public safety is ensured. Investigations are carried out for the Police Department on fires and explosions other than in mines, and expert evidence given in Coroner's inquiries dealing with arson, accidental fire, and explosions, murder and accidental fatalities, involving explosives and inflammable liquids and dangerous goods. Instructions are regularly given to Police Officers on explosives and removal of explosives in safe-breaking cases. Naturally the Senior Analyst in this section serves on all relevant State and Standards Association committees.

From this outline it can be seen that the Chemists of the Mines Department laboratory are endeavouring to keep pace with the general progress of their fellows in other disciplines and to render that service to the mining industry and the State which they feel the public needs. They have some pride in that within their laboratory is bridged the gap between the technique of the ancient fire assayer and the electronic determinations of the modern nuclear space age.

Current Trends

Since the end of World War II we have come to think of ourselves as living in a Free World quite distinct from that behind the Iron Curtain, but in mining, because of the law of supply and demand, and the various channels through which trade can flow, such distinction is not as clear cut as we might wish or think. Imposition of sanctions, once thought an effective weapon of defence against the menace to our freedom and way of living, now seems futile, particularly when Russia, China and their satellite countries have expanded both their knowledge of mineral resources, and their mineral productions, with

such speed that their productive potential may now equal that of the Western world which so heavily outweighed it but a few short years ago. The U.S.S.R. applies geochemical prospecting most extensively. Application of metallometric surveying was made mandatory in geological surveying and exploration on any scale and success must be judged on published results.

"In a drive to gain maximum knowledge of its indigenous mineral resources the U.S.S.R., according to an official report of the Soviet Government released last November, employed 398,000 people in 1958. This army of highly trained earth scientists of every type, chemists, semi-skilled technical personnel and labourers operated with a budget equivalent to about 1% of the country's Gross National Product . . . in a modern industrial society consumption of energy reflects the level of industrial production . . . in 1965 consumption of energy in the U.S.S.R. will be about 58% of the United States total for that year . . . the Soviet Union possesses the world's second largest ferrous metallurgical industry, being surpassed only by the United States . . . a large nation which spends a fortune in manpower and capital to locate, investigate and develop its mineral resources . . . a nation well endowed in minerals . . . which has used minerals to exert economic pressure or gain political advantage" (Anonymous, 1960a).

In some areas of China 70% of the population has been involved in prospecting for new mineral deposits. The Chinese Geological Service has 270,000 employees and workers (23,000 specialists including 12,000 geologists). "Anyone can visualize the consequences of turning 60 million Chinese from agriculture to prospecting, mining, and metallurgical operations, during the 'leap forward' year 1958, coupled with the report that China has increased her domestic production of mining machinery by 80% in 1959 over 1958 and has also been a substantial importer of machinery" (Alexandrov, 1960).

Thus it can be understood why, for instance, Chinese coal production rose in 1959 to a total of 348 million tons; it now exceeds that of Britain by 70%, and is second only to that of the U.S.A.

The same picture applies to other minerals and metals production. For example, 20 years ago Germany produced 20,000 tons of a world total of 32,000 tons of magnesium, the metal now coming so much to the fore in castings and alloys. In 1959 of a world production of 92,000

tons, 45% was produced by the U.S.S.R. and 30% by U.S.A.

An American team of engineering and education experts who visited the U.S.S.R. in 1960 at the invitation of the Soviet Ministry of Higher and Secondary Education, and sponsored by the National Science Foundation, reported that the Soviets are producing 250,000 industrial technician graduates each year compared to 15,000 in the U.S.A., but that in their opinion not more than 1000 of the U.S.A. graduates are trained as well as those of the Soviet. Engineering schools "project" research (basic and applied) expenditure in 1958 was \$70.9 million (Anonymous, 1960b).

However, as some counterbalance to any threat to world's stability from this great upward leap in production behind the Iron Curtain, there is the increased demand and consumption arising from the tremendous prospective growth in world population, and the rising standard of living behind the Iron Curtain and in newly emergent and economically undeveloped countries.

It appears then that we are in a highly competitive world situation and, if we want to help to maintain our position, we must realize and properly appreciate the importance and impact of technology. The aim of the mining engineer and the chemist here, as in other democracies, must be to develop our mineral resources to help support the expanding economy, and assist human welfare, and to encourage, within our Western system of free enterprise, as distinct from the Communist monopolistic system, greater investment in our mining industries and more research in our mineral sciences. It can be done. It is being done. In the last 17 years Australia's mineral production increased by £A200 million. Let us look at the position with respect to the fuels, the metals and the non-metals.

Coal constitutes 91.8% of the world's known reserves of fuel, oil 3.1%, natural gas 1.9%, peat 1.4%, methane in coal 0.9% and oil shale 0.9% (Andrews, 1960). In the field of Australian fuel we find that, despite the inroads of imported oil and the development of hydro-electric power in New South Wales and Victoria, the coal potential of Australia is an important economic factor in the rapid growth of secondary industries. The black coal industry has made a remarkable recovery, effecting a substantial reduction (12½%) in cost. Reorganization, improved efficiency, and mechanization have increased production per man shift to 6.11 tons. In N.S.W. uneconomic mines have been

closed down, underground collieries have been reduced from 140 to 102, employees from 20,000 in 1952 to 13,000 in 1960, and yet coal output has increased from 14.3 million to 15.8 million tons. Thirty-two million pounds have been spent on equipment, 81% of the coal won comes from highly mechanized collieries, and 30 washeries produce cleaner, lower ash coal, saving transport and ash disposal costs. Large electric generating stations erected, and to be erected, on the coalfields save transport and will ensure a continuous demand for coal. It has been shown that, used in properly designed and maintained appliances, coal is at least as efficient as oil and does not create a greater smoke problem than oil (Anonymous, 1959). Chemicals from coal are more varied and valuable than those from oil, but the petro-chemical industry is stronger, perhaps due to its greater research drive, than the coal chemical industry.

It would greatly help coal to compete successfully with oil as industrial fuel if, by cheap conversion, it could acquire the ease of handling and control which fluid fuels possess. Complete gasification-of-coal units on our coalfields, with a grid pipeline system similar to the electricity grid, is a possibility. Hydraulic pipe-line transport of coal itself, the further development of pulverized coal and colloidal coal-oil combustion units, and the use of fuel cells using coal as the fuel anode (Mills, 1960; Anonymous, 1960*d*) could help. Research is continually in progress on the storage of coal (prevention of spontaneous combustion), the manufacture, purification, quality and use of coal gas, coke, tar and even ash, as instanced in the new "Stretford" gas purification process (Anonymous, 1960*e*), and the effect of particle size distribution of blends of coking coals on coke quality (Anonymous, 1960*f*).

From time to time we have heard gloomy predictions as to the depletion of the world's supply of oil. Although the use of non-traditional sources of power must increase, liquid fuel may always be supreme in road and air transport, just as it seems that coal will be the primary source of power for many years to come. So far Australian natural oil and gas exploration has not yielded very much and our oil shale industry has closed down, although the shale worked was rich, averaging over 100 gallons to the ton; but there is plenty of time and we are not without hope. Much of Australia has still to be tested. Known world reserves of oil shale amount to one million million tons. The richest deposit in the U.S.A. is that at Green River, Colorado, covering 3000 sq. miles

and containing six times as much oil as all the wells in the world had produced by 1950, so that the U.S.A. need not worry overmuch about depletion of her natural oil reserves (Caldwell, 1960). Our Laboratory once carried out a lot of work on New South Wales oil shales. It is now just as busy with natural gas analyses.

If we now turn to the metals, technological progress is creating new opportunities for the older major metals, copper, lead, tin, and zinc, the light metals, aluminium, titanium, magnesium and scandium, the steel industry metals iron, manganese, nickel, chromium, cobalt, tungsten, molybdenum, vanadium, columbium, tantalum, and silicon, and the newer glamorous metals alike. Losses in the use of lead in cable covering and building are balanced by the growth in use in batteries, petrol, enamels, glazes, and electronics. The Copper Products Development Association has several projects under consideration, stainless copper, copper alloys of iron and steel (Anonymous, 1960*g*) and with alumina for electric power uses and chemical uses in industry and agriculture. It is interesting to note that an electric racing car has been built with power provided by prototype fuel cells using oxygen at 9 p.s.i. and zinc. High capacity of the unit in small space, plus operation at normal temperature and pressure, could make it a serious contender in the mobile power field (Anonymous, 1960*h*).

The light metals and their alloys are finding uses principally in air and road transport, building, structural, protective pigments, canning materials, electronics, chemical processing equipment and nuclear industries. Because of its high strength: weight ratio and resistance to corrosion, each 1 lb. of titanium saves about \$300 in additional pay load in the life of an aircraft. The new Douglas DC. 8 jet contains 2000 lb., the Convair 2500 lb. Volkswagen consuming 1300 tons of magnesium per year is the greatest single outlet for that metal. Uses are being investigated for scandium, which has a density comparable with aluminium but a melting point of 1550° C. or 2½ times that of aluminium.

In the steel industry, where research and development are continuous, world production in 1959 reached a total of almost 318 million tons, using one ton of manganese to 23 tons of steel. Nickel alloys are used in rockets and missiles, automobiles, batteries, electronics, and architecture. The properties and uses of tungsten (m.p. 3410° C.), molybdenum (2510°) and vanadium (1725°) are well known. These and columbium, the lightest of any engineering

metal retaining strength at jet end missile temperatures, and tantalum all have their respective and special uses as refractory metals in this burgeoning atomic energy and space age. The nuclear metals are uranium, zirconium, hafnium, lithium, beryllium, thorium, the lanthanons, ytterbium, caesium and rubidium. Of these we find zirconium not only used in refractories, foundries and ceramics, but in reactors for submarine propulsion. Hafnium has advantages over other materials in control rods in nuclear reactors. Lithium aluminium alloys are used in high performance aircraft and missiles and lithium chemicals in rocket propulsion. Beryllium in spite of its toxicity is used in gas cooled reactors and as shields in U.S.A.'s manned space capsules. Caesium compounds are used in photoelectric cells, infra-red photography, signalling devices, scintillation counters, vapour rectifiers, radio tubes, micro-chemical reagents, special storage batteries and rocket fuels, and a caesium thermionic cell has been used in the first direct conversion of nuclear energy into electric power. A potential use for this metal is in ion propulsion engines for space travel.

Then there are the electronic minerals (micas), and metals which can be produced in a high degree of purity, Cd, Hg, Se, Ge, Si, Te, Ga, In, Re, Tl, and Ra.

Mica scrap can now be chemically treated and the resulting pulp formed into a continuous sheet, by methods similar to those used in paper manufacture, for use in the electrical industry.

Most of the various properties and uses of these metals and their compounds are well known, but some interesting ones might be mentioned. Silicon is used on a large scale as a semi-conductor in transistors and rectifiers for highly sensitive electronic devices and in solar cells. Its use as ferro silicon in the steel industry is well known but hyper-eutectic silicon alloys (up to 16% Si) may possibly become a substitute for cast iron in automobile engines.

Tellurium's present use is chiefly in copper alloying, rubber industry, and thermo-electric devices but beryllium telluride is believed to have startling possibilities in the development of non-mechanical refrigeration units and in the generation of electricity from solar and atomic reactor heat sources using no mechanical parts.

Gallium melts at 85° F. but does not boil until 3600° F. and expands on solidification. It has to be handled in special tantalum lined containers which resist its corrosive action, but its potential uses in metrology are obvious.

Gallium compounds have a wide variety of uses, the phosphide is being developed by the U.S. army signal corps for aero space uses.

The chemical and metallurgical materials potash, soda, antimony, sulphur, boron, bismuth, fluorspar, barytes and phosphates have well known uses in the chemical, metallurgical, printing, pigment, plastics, rubber, ceramics, glassware, agriculture, pharmaceutical and atomic energy industries. The remaining minerals include the clays and clay shales, the insulants, and refractories such as asbestos, vermiculite, perlite, sillimanite and graphite; the gem stones, and the abrasives sand, garnet, and pumice with the applications of which most are familiar (Anonymous, 1960j).

Merely to show possibilities, may I say that at a lecture I attended in 1949 at the Fourth Empire Mining and Metallurgical Congress in England, Sir John Cockcroft demonstrated an alloy with certain required properties demanded by the Government for which he had theoretically and accurately predicted the composition from known properties of metals and their lattice structures.

Future Outlook

The demand for minerals moves with general economic trends and is governed by technological and political developments. The rapid development in travel, terrestrial and space, and the upward surge in living standards will demand more metals, alloys, and chemical compounds with tailor-made properties in ever increasing variety and quantity than we could conceivably have required even a few years ago. It is obvious that the establishment of new sources of these materials depends first on widespread analytical investigation, and then on the development of adequate extraction methods. Old methods of prospecting must be improved and new methods developed and used. The Metallurgist must improve extraction and the Chemist must seek better and quicker means of determination.

General aerial reconnaissance which has already been used in Australia with suitable instruments, such as gravity meters, could be followed by general ground seismic exploration and prospecting with portable instruments such as a beryllometer (Anonymous, 1960k), transistor operated geophysical units, chromatographic methods, and metallometric surveys. Prospecting methods based on the scientific analysis of the different isotopes of oxygen in rock formations and their relation to the extent to which they were heated and permeated

by hot mineral bearing fluids hundreds of millions of years ago are being developed.

During the past few years a considerable Uranium mining and metallurgical industry has been developed in relation to atomic energy. This would have been impossible but for the introduction on an industrial scale for the first time in the mineral chemical industry of new methods of extraction using either organic solvents or organic ion exchange resins. These specially selective processes will no doubt help in their turn in the extraction of other minerals from their lean ores.

Mining cannot exist without water. Even if one or two of the mining processes themselves do not use water (such as gold concentration by dry blowing) the operators must have it to live. It can be filtered from solids but sometimes the soluble salts of available water are too high for all ordinary purposes. One promising method of demineralizing such water to a useful state is by electric dialysis. The National Chemical Research Laboratory of the South African Council for Scientific and Industrial Research, Pretoria, has shown that by use of ion selective membranes, 100,000 gallons per hour of brackish water can be reduced from a salt content of 3000 parts per million to a potable 500 parts per million, and at the same time produce a concentrated brine (Anonymous, 1960, 1960*m*). The use of cetyl alcohol in reducing evaporation losses from reservoirs is now well known. At Broken Hill, N.S.W., 200 million gallons of water were saved in six weeks in 1957 (Mansfield, 1960).

As far then as the mining industry and chemistry are concerned the outlook is awe-inspiring in its immensity and challenging. Great events are imminent which could plunge the world into utter depths of destruction, horror and despair, or lift it to immense heights of constructive development, attraction and delight beyond present imagination. We can only trust that the Supreme Being, whose wealth and variety of secrets seem the greater the more we probe them, will guide world leaders aright. Willy nilly we dare not cease endeavours to discover and use Earth's natural resources for the general betterment of mankind.

Since 1950 there has been an increased and significant fusion of the mining and chemical industries, chemical companies going into mining for the raw materials and mining companies becoming interested in chemical end products. This combination of interests is important to our welfare and will become stronger.

No progress, however, is possible without the vital human element, and the miner and the chemist must attract an adequate supply of recruits of the right type into their professions, not just by appealing to the romantic, the adventurous, or the idealistic in their natures, but by offering the best tuition possible, good career prospects, and ever safer working conditions. The newcomers must be made aware that even in large-scale enterprises the individual is not lost in the crowd and no longer essential.

"Creative thinking is the province of the individual . . . association with a group does not relieve anyone of personal responsibility . . . because we can employ tools, we tend to forget that they were fashioned to aid, not to replace, the human hand . . . no machine ever devised has acquired the great human virtues of courage, faith and resolution in the face of adversity . . . this country was not built by timid souls . . . there is hardly a successful venture in our history, industrial or national, against which excellent arguments, highly logical arguments, could not have been advanced at the outset . . . it is the responsible individual's role to evaluate the scientific tools at hand to the end that our technology is not seen as an end but as a means . . ." (Dupont, 1960).

It may not seem quite the same to young people who today nonchalantly accept the present way of life, but to those of us who have seen the fantastic progress and changes since the turn of the century, the future, undoubtedly in their hands, seems of immense opportunity and promise.

All sciences are becoming so inextricably entangled that it is increasingly difficult to define lines of demarcation between the various disciplines. This necessitates a widely based general scientific knowledge in early education before specializing in particular fields.

Necessary specialist societies cater for and encourage research and development in their own particular fields, but as a general forum for interchange of knowledge of progress in the various disciplines such a body as this Royal Society of New South Wales, with its members drawn from every profession and walk in life, united in common concern for science, affords means for the healthy well balanced scientific progress so essential to the ultimate common weal. Its members naturally include representatives of both the mining and chemical professions and in the Chemical Laboratory of the N.S.W. Department of Mines we are

striving in our humble way to fulfil those functions we feel the mining industry demands of us.

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A Useful Variation of the Graphical Proof of the Biot-Fresnel Law

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ABSTRACT—The law is proved on a crystallographic plane coincident with the plane of stereographic projection.

The investigation of extinction phenomena in petrological and mineralogical studies is an essential part of an examination under the petrological microscope, and if universal stage techniques are used procedure is completely dependent on extinction. Therefore, in discussions of optical theory, even at an elementary level, the property should receive due attention.

Early in the last century, it was known that light transmitted through crystal sections vibrated in directions which were strictly controlled by the crystal structure. Biot (1820) determined experimentally, and Fresnel (1827) proved theoretically, that for light of perpendicular incidence, the extinction directions in any biaxial crystal section bisect the angle between the traces made on it by two planes, each of which contain an optic axis and the section normal.

Fletcher (1892) showed that the optical properties of a crystal could be identified with the geometry of a triaxial ellipsoid, the "optical indicatrix". This surface was, as Fletcher himself pointed out, the ellipsoid of polarisation of Couchy, the ellipsoid of indices of MacCulloch and the index ellipsoid of Liebisch. In a classical paper by Phemister (1954), the "Fletcher Indicatrix" surface was bound up with the electromagnetic theory of light. Since this optical figure, for which Phemister would prefer the name "wave-normal ellipsoid", is completely established, the Biot-Fresnel law is simply and adequately proved by means of stereographic projection. Recently published text books use the law but do not prove it (de Jong, 1959; Hartshorne and Stuart, 1960). Wahlstrom (1960) gives a three-dimensional clinographic projection diagram, but his proof

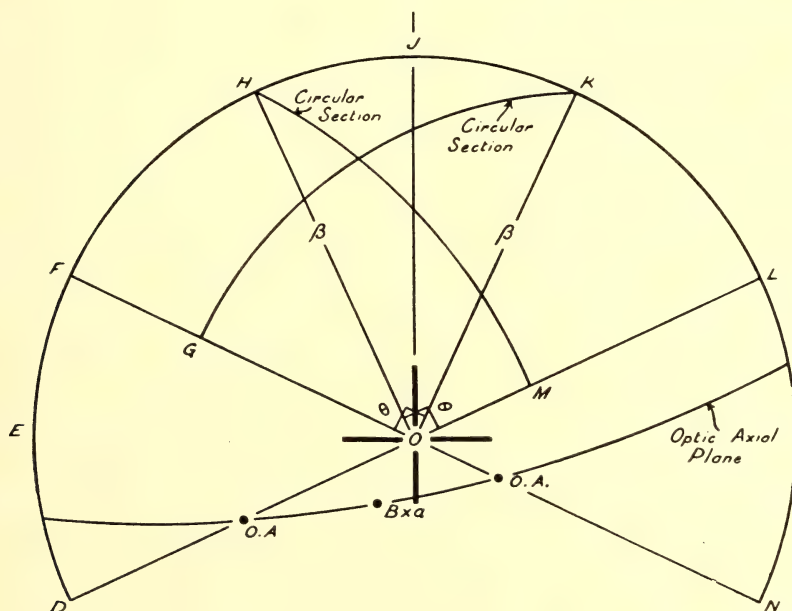


FIG. 1

and one given earlier by Johannsen (1918) lack clarity because the crystal plane for which extinction directions are determined has random orientation *in the respective projections*. Therefore, the following graphical proof is brought to the notice of readers.

In Figure 1 a *random* crystal section is represented stereographically, not cyclographically (Fisher, 1953), by the great circle arc and reference circle DHKN. For the purpose of discussion any two points within the circle except the centre point *O* may be chosen to represent the stereographic poles of the optic axes (O.A.). Each will lie on a radius of the reference circle. The great circle arcs MH and GK, of which the optic axes are poles, are constructed. Then OH and OK represent the intersection of the circular sections of the indicatrix with the plane of the random section. The constructed right angles KOF and HOL include the angle HOK, therefore, the angles FOH and LOK are equal. OH and OK, equal radii β , of the indicatrix, must lie symmetrically about a semi major or a semi minor axis of the elliptical section coincident with and representing the random section, DHKN. OJ, a semi axis, is constructed and consequently the angles JOF and JOL are equal, i.e. "an extinction direction bisects the angle between the traces on the section of two planes NF and DL each of which contains an optic axis and the section normal *O*".

If the stereographic pole of the optic axis on OD be moved to D, and a new optic axial plane

be projected, Figure 1 will illustrate a section *containing one optic axis*; the arc MH will coincide with OH. The positions of vibration directions will not change.

With one optic axis represented by a stereographic pole at D and the other by a stereographic pole at F, the case of an *optic normal* section may be examined.—The arcs MH and GK will coincide with the radii OH and OK respectively and the stereographic pole of the acute bisectrix will lie in a vibration direction at E.

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The Stratigraphy and Structural Geology of the Manilla-Moore Creek District, N.S.W.

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ABSTRACT—The Woolomin Beds are shown to be of Ordovician-Silurian age and the limestone horizons within the Tamworth Group are recognized as biostratigraphical and not lithological units. Particular attention is given to the problems of Upper Devonian stratigraphy, the Manilla Group being redefined to consist of the Baldwin Formation and Mandowa Mudstone. The Baldwin Formation is taken to include the lower strata of the earlier Barraba Mudstone. It is recommended that the use of the term Barraba Mudstone be discontinued. The Klori Anticline, Mandowa Syncline and Attunga Fault are recognized as important new structural features and the Yarramanbully Anticline, the Namoi Fault and the Peel Fault System are studied south of the Namoi River. The tectonic evolution of the Tamworth-Manilla district and its relation to the tectonic evolution of New England are outlined.

Introduction

The area under consideration is situated between Manilla and the Namoi River to the north and the Peel River and Moore Creek to the south. It extends from near Somerton in the west to the margin of the New England Batholith to the east. The region covers the eastern three-quarters of the Attunga one mile to the inch military sheet and portions of the adjacent Manilla and Tamworth sheets.

Benson (1915, pp. 541-544) summarized the earlier geological literature on the Tamworth district. He examined the areas between Tamworth and Moore Creek and north of the Namoi River in detail (1915, 1917*a*). The work which he had done between Moore Creek and the Namoi River was published (1917*b*). Brown (1942) studied the Tamworth Series north of Attunga in detail, recognizing three horizons of limestone. Voisey (1958*b*) identified the Manilla Syncline as the major structural feature north from Manilla. He also named the Yarramanbully Anticline and the Namoi Fault which have been mapped southwards in the area under discussion. Crook (1959) studied the area south of Tamworth and many of his conclusions are of importance in this study.

This publication fills in the gaps in the work of Benson, referred to above, linking his more detailed studies and those of Brown (1942) and Voisey (1958*b*). In addition, the area north of Tamworth, mapped by Benson (1915) has been examined in part and conclusions arising from this, in the light of our fuller knowledge of the structural evolution of New

England, are presented. The author has also examined the area to the west of the Attunga-Manilla Road, which had not previously been studied, joining this study to the northerly continuation of the Werrie Basin (Carey, 1934). In addition, the author has mapped the rocks of the new England Batholith east of the present area.

Stratigraphy

The stratigraphic rock units adopted in this study are as follows (in descending order):

Carboniferous

Burindi Group

Devonian

Manilla Group

Mandowa Mudstone

Baldwin Formation

Tamworth Group

Silurian

Woolomin Beds

In addition to these rock units, three time-rock units are recognized within the Tamworth Group, namely the Moore Creekian, Sulcorian and Neminghaian stages. These are the three limestone horizons within the Tamworth Group and comprise only portion of that Group.

Woolomin Beds

The Woolomin Beds occupy a considerable area of New England; in the present area they occur east of the Peel Fault System and are bounded to the east by the New England Batholith. Crook (1961*a*, pp. 175-176) summarized the nomenclature used for these rocks

by various authors and proposed the term Woolomin Beds. This terminology is appropriate and is followed in this paper.

The structural complexity of the Woolomin Beds renders their detailed study very difficult. Their general and lithological features have been described by Benson (1913*a*, p. 496; 1913*b*, pp. 570–572; 1913*c*, pp. 707–708; 1915, pp. 546–548; 1917*a*, pp. 228–233; 1917*b*, p. 695). The characteristic lithology consists of jaspers and quartzites with spilites, greywackes and generally very highly sheared argillaceous rocks. They are intersected by numerous quartz veins and many of the rocks have undergone marked silicification.

In addition to the normal lithological association of the Woolomin Beds, limestone has been observed at the following localities (grid references to Australian one mile to the inch series, zone 8, sheet no. 321, Attunga): L1, 934904; L2, 927890; L3, 916843; L4, 916840; L5, 998827; L6, 910875; L7, 908793; L8, 918784; L9, 922783.

These localities are shown on the accompanying geological map. L6 is the most extensive occurrence, lying to the west of the main development of serpentinite, north of the head of Yarramanbully Creek. The limestone here is about 50 ft thick, extending about three-quarters of a mile south of the above grid reference, thinning to the south. L5 and L7 are smaller, L1 and L4 are small outcrops, and L2 and L3 are of very minor extent. The relationships with adjacent strata are best seen at L7, it being impossible to determine relationships at some of the other localities. The masses of limestone at L7 are interbedded with the more characteristic rocks of the Woolomin Beds, as part of the normal sequence and hence the limestone bodies are considered to be part of the Woolomin Beds sequence in this area.

Of these occurrences, Carne and Jones (1919) recorded L1 (p. 219) and L7, L8, L9 (p. 256). They considered the latter occurrences to be the northerly continuation of the limestone south of Willow Tree Creek and in their opinion all bodies were of Devonian age. In addition (p. 219), they recorded two small lenticular beds of limestone on the western side of Wiseman's Arm Creek, in portions 55, 91, and 82, Parish Hallor n.

Benson (1917*b*, p. 695) recorded lenticular masses of limestone among the Eastern Series which are "well seen along the valley of Wiseman's Arm Creek". His accompanying map (p. 694) showed limestone traceable in

the Eastern Series, although no specific localities were indicated. He stated (p. 695) that this limestone probably belongs to the Nemingha horizon which he considered to be of Lower Middle Devonian age.

The limestone bodies have not been examined in detail for palaeontological evidence. However, the presence of *Halysites* sp. (with *Favosites* sp. and *Heliolites* sp.) at L4 and L6 indicates that the limestones are of Ordovician-Silurian age. Further search may reveal the presence of rugose corals at the various localities which might enable the age to be determined with greater precision. The fossil occurrences are probably near the top of the sequence (see also Voisey, 1959*b*, p. 194). The only previous record of Lower Palaeozoic fossils from northern New South Wales is that of Whiting (1954, p. 87), who recorded dendroid *Favosites* sp. and *Tryplasma* sp. in dark limestone at Jackadgery on the North Coast of New South Wales. These were stated to be of Silurian and possibly Upper Silurian age.

The presence of limestone in the Woolomin Beds throws light on the problem of the presence of rocks of the Tamworth Group faulted into the Woolomin Beds. In defining the Woolomin Series, Benson (1913*a*, p. 496) considered the Series to be of Lower Devonian age. Later (1915, p. 546), he stated that the rocks east of the Serpentine Line are "so intensely folded and faulted, and have thrust in among them so much that seems to be derived from the Middle or even Upper Devonian series, that it has not seemed worth while, at present, to attempt to disentangle the Woolomin Series from the others, if such a series should really exist". He named the whole complex of rocks east of the Serpentine Line the Eastern Series, the term Woolomin Series being restricted to rocks thought to be of Lower Devonian age, these being included within the Eastern Series.

Brown (1942, p. 176), after demonstrating that the Tamworth Series extended into the Lower Devonian, deduced that the older Woolomin Series was pre-Devonian in age. In the sense in which Benson (1915) used the term Woolomin Series, it would thus be applied to the rocks of pre-Devonian age east of the Serpentine Line and the Eastern Series would include both these and the unfaulted representatives of Devonian rocks occurring more typically west of the Serpentine Line.

The record of limestone masses among the Eastern Series by Benson (1917*b*, p. 695) has been mentioned above. These led Benson to state that "the crushed and altered rocks of the

Eastern Series here belong, apparently, to the Lower Middle Devonian formation in great measure". Thus he would not have included these in his Woolomin Series.

This study has shown that these limestone bodies are pre-Devonian. This suggests that further examination of the Woolomin Beds in other areas may reveal that many of the beds "infaulked" among Benson's Woolomin Series, to give the complete Eastern Series, are of the same general age as the Woolomin Series. An example is the lenticular mass of limestone recorded by Benson (1918, pp. 328-329) from portions 52 and 146, Parish Nemingha, 300 yds east of the serpentine.

Thus it is considered that the difficulties which prompted Benson in 1915 to propose the term Eastern Series to include the Woolomin Series and younger rocks occurring more typically west of the Serpentine Line may yet be resolved. At least in the present area, which represented one of Benson's chief difficulties in this respect, the problem no longer exists.

Tamworth Group

The Tamworth Group is regarded as Lower Devonian-Middle Devonian in age. The northernmost occurrence is south of the Namoi River east of Manilla and the Group occupies a belt south of this, bounded by the Namoi and Attunga faults, with a maximum width of approximately four miles, east of Attunga. Strata of the Tamworth Group also occur east of the Namoi Fault south of Spring Creek.

Benson (1913*a*, p. 496) gave a section of what he considered to be the most typical and complete section of the Bowling Alley or Tamworth Series at Bowling Alley Point, with a total thickness of 10,000 ft. Later (1913*b*, pp. 572-580) he gave a complete description of the Bowling Alley Series. In 1915, Benson (1915, p. 548) recognized three horizons of limestone in the Tamworth Series, in place of the single horizon formerly recognized, placed, in probable chronological order, as follows: the Nemingha Limestone, the Loomberah Limestone and the Moore Creek Limestone. The whole of the Tamworth Series was thought to be Middle Devonian in age. Benson (1917*b*, p. 698) assumed that the limestone north of Attunga belonged to the Moore Creek horizon, although the presence of *Phillipsastraea* sp. and other forms suggested to him that the Loomberah Limestone might also be represented.

The possibility of establishing the stratigraphical relations of the various limestones in

the Tamworth Series led Brown (1942) to undertake her studies in the Attunga district. The Rugosa collected by Brown were described by Hill (1942) and the field relationships enabled Brown to divide the Tamworth Series north of Attunga into the Nemingha, Sulcor and Moore Creek stages.

Hill (1942) deduced, from a study of the Rugosa, that

1. The Nemingha (*insigne*) fauna is Lower Devonian or possibly early Couvinian.
2. The Loomberah (*Eddastraea*) and Sulcor (*Eridophyllum*) faunas are both early Couvinian, not necessarily on the same horizon, and
3. The Moore Creek (*Sanidophyllum*) fauna is Givetian in age.

Voisey (1958*a*, p. 175; table C, p. 174) renamed the stratigraphical units proposed by Brown. In table C, Voisey has shown the Tamworth Group as equivalent to the Tamworth Series of Benson, Brown and Browne (David, 1950, p. 236), containing the following three formations:

Moore Creek Limestone
Sulcor Limestone
Nemingha Limestone.

Later, Voisey (1958*b*, p. 209) included the Tamworth Common Cherts or Tamworth Cherts as a formation within the Tamworth Group. This referred to the cherts overlying the Moore Creek Limestone which are well known from their occurrence at Tamworth Common. The Tamworth Group was defined by Voisey in anticipation of later work enabling a full sequence of constituent formations to be defined (Voisey, 1958*a*, p. 175). This has now been done by Crook (1961*a*).

It has not been possible to define strictly lithological units within the Tamworth Group north of Tamworth. This group is here regarded as a single mappable unit, consisting dominantly of the lithological association of limestone and chert.

Although the distribution of the various limestone masses within the Tamworth Group is shown on the accompanying map, this does not imply that the limestones constitute rock units in the sense of the Australian Code of Stratigraphic Nomenclature (1959). Brown (1942) showed that three horizons of limestone are present in the Attunga district. The evidence for this is primarily palaeontological since nowhere in the region from Tamworth to Manilla can the presence of three horizons in

sequence be shown in the field. The presence of at least two horizons can be demonstrated in two localities, north of Sulcor Quarry and north-east of the Manilla Road, two and a half miles from Attunga. Thus the basis for distinguishing the three limestone horizons is palaeontological and these methods must also be used in determining to which horizon a particular outcrop should be assigned.

Hence, in accordance with the Code (1959, p. 64), it is here proposed to use time-rock terms for the limestones that were mapped by Brown (1942). The terms Moore Creekian Stage, Sulcorian Stage and Neminghaian Stage are not used in the same sense as Brown, being restricted to the limestone masses, whereas Brown included adjacent cherts in the appropriate stage. It is not possible to do this on a larger area than that studied by Brown since limestone masses, necessary for time-rock determinations, are not as abundant. This nomenclature involves the setting up of a local time-scale as provided for in the Code (1959, p. 69). In accordance with the evidence of Hill (1942), the Moore Creekian, Sulcorian and Neminghaian stages are considered, respectively, to be Givetian, Couvinian, and Coblenzian or possibly early Couvinian in age. Each stage corresponds, in time, with portion of the European equivalent. The stages are distinguished on the basis of the faunal lists of Brown (1942, pp. 169, 170, 172).

The accompanying map includes the area mapped by Brown (1942, p. 168), the horizon to which she assigned each limestone body being shown. In general, the other limestone masses have not been allocated to a particular stage, as this would be beyond the scope of this study.

The age of the limestones south of Moore Creek, originally surveyed by Benson (1915), has been indicated on the map. These are the type Moore Creek limestones, characterized by such forms as *Sanidophyllum davidis* Eth. fil. and *Spongophyllum giganteum* Eth. fil. (1915, pp. 551-552). In addition, the limestone near Willow Tree Creek is assigned to the Moore Creekian Stage on the basis of the presence of *Amphipora* sp., a form which Brown (1942, p. 172) included in the list of fauna characteristic of the Moore Creek Stage, but not the Sulcor and Nemingha stages (pp. 170, 169). Benson (1917b, p. 695) stated that this limestone probably belongs to the Nemingha horizon and Brown (1942, p. 170) adopted this conclusion.

The presence of *Pseudamplexus princeps* (Eth. fil.) in a large limestone body to the south of Yarramanbully Creek indicates that this

belongs to the Sulcorian Stage. Brown (1942, p. 173) has assigned the large mass of limestone to the west of Yarramanbully Road to this stage on her sections, although they are outside the area shown on her map. This suggests a possible Couvinian age for many of the limestone occurrences north and east of the area surveyed by Brown.

There is no evidence to suggest that the limestones are reef complexes. In a few instances the limestones occur as continuous beds which exhibit little change in thickness and no lateral facies variation to be expected in reef complexes or bioherms. In the other cases in which there are numerous small masses of limestone, this multiplicity is ascribed to tectonic features, not to the limited lateral extent one would associate with a reef origin. I. A. Browne (1959, p. 115) has pointed out that the Devonian limestones at Taemas are well-bedded deposits. It is suggested that the limestones formed under essentially similar conditions in both regions, as outlined by Browne (1959, p. 126) for Taemas.

No continuous sequence of beds in the Tamworth Group has been measured because of the extensive deformation which has also obscured its relationship with contiguous formations. It is separated from the older Woolomin Beds by the Peel Fault System and in only one place was it followed upwards into the Baldwin Formation. This was east of the Namoi Fault, between Attunga and The Horse Arm creeks. Here the base of the Baldwin Formation is approximately 7,000 ft above the limestone of the Moore Creekian Stage near Willow Tree Creek. In this case there may be some repetition of portions of the Tamworth Group by strike faulting.

Manilla Group

The Manilla Group consists of the Baldwin Formation and the overlying Mandowa Mudstone. It is regarded as Upper Devonian in age, the palaeontological evidence for this being as follows. *Leptophloeum* sp. is found through most of the sequence, a genus which Tachibana (1959, pp. 31-33) states is characteristic of the Upper Devonian of Eastern Asia and Australia. Pickett (1960) described a new species of clymeniid, *Cymaclymenia borahensis* from the Borah Limestone, correlated with the Kiah Limestone of Crook (1961b), considered to occur within the Mandowa Mudstone in the area under discussion. Pickett (1960, p. 238) also records *Platyclymenia* sp. from the Baldwin Formation in Catong Gully. Both of these forms are Upper Devonian in age.

Benson (1913*a*, p. 495) included the Barraba or Nundle Series and the Baldwin Agglomerates in his classification of the sedimentary formations developed prior to the folding in the Great Serpentine Belt. He considered the former to have a maximum thickness of at least 13,000 ft. Later (p. 503) he stated that there is probably much repetition in the Nundle Series. Benson (1915, p. 577) again recognized two divisions of the Upper Devonian Series. However, he extended the term Barraba Series to comprise the whole of the Upper Devonian, recognizing the Baldwin Agglomerates merely as a basal zone which may or may not be present. He used the terminology Barraba Mudstones for the upper part of the Barraba Series. This was followed in his later discussions.

David (1950, p. 251) used the terminology Barraba Series, consisting of the Baldwin Stage and an upper or mudstone stage. Osborne (1950, p. 10) discussed the Baldwin Series and Barraba Series as separate stratigraphical units of equal status. Voisey (1958*a*, 1958*b*) defined the Baldwin Formation and Barraba Mudstone as formations constituting the Manilla Group in the Manilla Syncline. Crook (1961*b*) grouped the Upper Devonian sediments of the Tamworth-Nundle district into the Parry Group, containing

two main formations, the Baldwin Formation, and overlying it, the Goonoo Goonoo Mudstone. The relationship between these various schemes is shown in Table 1, together with the terminology here adopted.

In proposing the Baldwin Formation, Voisey (1958*a*, p. 175; 1958*b*, p. 209) was unable to designate a type section as required by the Australian Code of Stratigraphic Nomenclature (1959, p. 67) because extensive faulting made it virtually impossible to measure stratigraphical sections (1958*b*, p. 210). It was anticipated that later work elsewhere would enable a type section to be defined. Crook (1961*b*, p. 192) stated that the Baldwin Formation only required designation of a type section to be completely acceptable under the Code. He later (p. 204) defined the type section of the Formation at Silver Gully, south of Tamworth.

Voisey (1958*a*, p. 175) stated that near Manilla the sudden change from coarse beds to mudstones is so well marked that it shows up physiographically and is an easily mapped junction. This junction was taken as the top of the Baldwin Formation. He (1958*b*, p. 210) noted a number of breccia or greywacke beds in the mudstone sequence, mainly in the higher parts of it, the total percentages being much

TABLE I

RELATION BETWEEN VARIOUS SCHEMES OF NOMENCLATURE PROPOSED FOR THE UPPER
DEVONIAN AND LOWER CARBONIFEROUS SEQUENCE (—K—L— = Kiah Limestone horizon)

Benson (1913a)	Benson (1915)		Voisey (1958a, 1958b)		Crook (1960b)		Crook as here interpreted		This paper	
Burindi Series	Burindi Series		Lower Burindi Group		Group	K—L	Group	K—L	Burindi Group	
Barraba Series	Barraba Series	Barraba Mudstones	Barraba Group	Barraba Mudstone		Goonoo Mudstone		K—L	Mudstone	Group	K—L
Baldwin Agglomerates		Baldwin Agglomerates		Baldwin Formation	Baldwin Formation	Baldwin Formation	Baldwin Formation	Baldwin Formation	Baldwin Formation	

less than in the Baldwin Formation. Crook (1961*b*, p. 192) stated that the top of the Baldwin Formation is readily identifiable throughout the Tamworth-Nundle district and also in the Manilla district. The top of the Formation was formally defined as the top of the last major arenite bed in the basal portion of the Parry Group.

The Baldwin Formation, thus defined, includes the greywacke beds in the mudstone sequence overlying the Baldwin Formation as mapped by Voisey (1958*b*) in the Manilla Syncline. The horizons taken by Voisey and Crook are not equivalent, strata of Voisey's Barraba Mudstone being included in the Baldwin Formation as defined by Crook.

The Baldwin Formation is here taken as extending from the top of the Tamworth Group to the top of the last greywacke bed in the overlying sequence. The upper limit is marked by a clear physiographic break on both limbs of the Klori Anticline. It is considered that the Formation is always developed above the Tamworth Group in southern and western New England. The present investigations have shown that faulting is responsible for the absence of the Baldwin Agglomerates in the places found by Benson (1915, p. 577).

The difficulties inherent in changing the sense in which Voisey originally defined the Baldwin Formation are resolved if it is recognized that his definition lacked designation of a type section, for the reason given earlier, and that such a section has been provided by Crook (1961*b*, p. 204), lithologically equivalent to the unit that is here considered desirable for the following reasons. First, this represents a distinct lithological and lithogenetic unit. There is a variation in the relative proportions of greywacke and mudstone through the sequence, but this is not a significant lithogenetic feature. Second, this unit could be generally readily recognized for mapping purposes. A problem in this regard would be presented in areas of flat-lying strata consisting of mudstone without greywacke, which could be representative of either a greywacke-poor portion of the formation or of the overlying formation which consists of similar mudstone. Third, it is essential to group all the mudstone-greywacke strata into one unit for mapping in more deformed regions, for example in the Yarramanbully Anticline. An example of the confusion that would prevail is provided by the strata of the Baldwin Formation in the Klori Anticline north of the Namoi River, forming the hills west of Spring Creek. Benson (1917*a*, p. 255) regarded these as

Baldwin Agglomerates on the basis of lithology. These can now be correlated with the mudstone-greywacke beds occurring in the highest parts of the sequence in the Manilla Syncline, which Benson (1917*a*, p. 250) assigned to the Barraba Mudstones.

The term Mandowa Mudstone is proposed for the lithological unit overlying the Baldwin Formation, extending upwards to the base of the Burindi Group. This is equivalent to the upper portion of the Barraba Mudstone. It is recommended that use of the term Barraba Mudstone be discontinued. The term Barraba Mudstone is old and well known but its use here would add to the number of meanings which this term has assumed in the past. Thus a new stratigraphic term, namely Mandowa Mudstone, is proposed. In addition, the rocks west of Barraba, regarded by Benson (1917*a*, p. 256) as the type for the Barraba Mudstones, may well belong to the Baldwin Formation as now defined.

The Mandowa Mudstone is named from its development in the Mandowa Syncline. The formation outcrops very poorly but future examination of the western limb of the Klori Anticline should enable a precise definition to be made. The provisional type section is on the western limb of the Klori Anticline immediately south of the Namoi River. The Kiah Limestone Member, a characteristic limestone horizon in the Goonoo Goonoo Mudstone to the south (Crook, 1961*b*, pp. 201–202) occurs within or slightly above the Mandowa Mudstone on the western limb of the Klori Anticline on both sides of the Namoi River.

Crook (1961*b*, p. 195) considered that in the Tamworth-Nundle district, the sequence between the top of the Tamworth Group and the base of the "Lower Kuttung Group" should be considered as a single group, the Parry Group. The Goonoo Goonoo Mudstone overlying the Baldwin Formation comprised the Barraba Mudstone and "Lower Burindi Group" in the sense of Voisey (1958*a*, pp. 175, 176). The terms "Burindi" and "Barraba" were stated to have no objectivity in the area discussed. Carey (1937, p. 350) mentioned the presence of current-bedding in the sandstones near the base of the Burindi Series in the Merlewood Section. Voisey (personal communication) has traced this and other features indicative of shallow water deposition north through the Keepit Dam area to Wean. This apparent shallowing of the seas to the west has made separation of the Mandowa Mudstone from the overlying formations quite clear in this region.

It is proposed that the term Mandowa Mudstone be used in areas in which an upper limit can be recognized at the onset of conditions of shallow water deposition. In other cases the use of the term Goonoo Goonoo Mudstone is appropriate. This scheme is illustrated in the last two columns of Table 1.

The Baldwin Formation and Mandowa Mudstone are taken to constitute the Manilla Group. As thus defined, it is identical in stratigraphical extent with the original definition of Voisey. The distribution of the Manilla Group is shown on the accompanying map and it is of extensive occurrence. The Baldwin Formation occurs on either side of the Tamworth Group in the limbs of the Yarramanbully Anticline, in the Manilla Syncline and in the axis of the Klori Anticline. The principal occurrences of the Mandowa Mudstone are in the Mandowa Syncline and the western limb of the Klori Anticline, from which it passes conformably upwards into the Burindi Group strata west of the present area.

Benson (1913*a*, p. 495) estimated a thickness of 3000 ft for the Baldwin Agglomerates and Voisey (1958*b*, p. 210) considered this a reasonable estimate. Crook (1961*b*, p. 204) gave a thickness of 3100 ft for the Baldwin Formation in the type section. The 2000 ft of Barraba Mudstone in the centre of the Manilla Syncline (Voisey, 1958*b*, p. 210) is now included in the Baldwin Formation and must be added to Voisey's earlier figure for the thickness of the Baldwin Formation in the Manilla district. The apparent thickness of the Baldwin Formation on the eastern limb of the Yarramanbully Anticline is much greater than the 5000 ft indicated above, but there is probably repetition by strike faulting.

The greywacke beds in the Baldwin Formation are subordinate in amount to the mudstone. Voisey (1958*b*, p. 210) stated that approximately 60% of the formation consists of mudstone and the present writer's observations support this conclusion. In addition, it must now be recognized that greywackes may be absent from considerable portions of the sequence.

The author intends to publish the results of a petrological study of the greywackes of the Baldwin Formation later. These exhibit many of the features of deep water sediments tabulated by Packham (1954, p. 467). They are medium to coarse-grained, poorly sorted rocks, the detrital fragments being highly angular. Characteristically, quartz is present only in very small amounts, or absent. The dominant detrital component is rock fragments, principally of andesitic origin. The following is an average

of the modal analyses of thirty-three greywackes: Quartz=0.5%; plagioclase=11.8%; rock fragments=64.4%; pyroxene=1.5%; opaque minerals=0.3%; matrix=19.5%; carbonate=1.6%; cement=0.4%.

Benson (1913*a*, pp. 495, 503; 1913*b*, p. 581) estimated that the Barraba or Nundle Series had a maximum thickness of over 13,000 ft but the maximum thickness measured by Crook (1961*b*, p. 195) for that portion of the Goonoo Goonoo Mudstone corresponding to the Barraba Mudstone was 1150 ft in the Timor Creek district. The thickness of the Mandowa Mudstone north of Somerton, using the Burindi Group boundary shown on Carey's map of the Werrie Basin (1934), is a little over 2000 ft. An accurate figure should be obtained when the boundary between the Burindi Group and the Mandowa Mudstone is mapped in detail. This supports Crook's drastic reduction of the original thickness proposed by Benson. The conglomerates taken by Carey (1937, p. 350) as the basal beds of the Carboniferous Burindi Series in the Merlewood Section are now considered to be the uppermost beds of the Baldwin Formation in that region; Crook (1961*b*, p. 193) subscribed to this view. The thickness of the Mandowa Mudstone here, before the onset of sediments of shallow water origin mentioned above, is of the order of a few feet.

Burindi Group

Benson (1917*a*, pp. 238-240; 1926, p. 38) recorded Carboniferous strata adjacent to the Serpentine Line north of the Namoi River. Voisey (1958*b*, Plate VI) mapped these Carboniferous strata between the Peel Thrust and the Fleming Fault, south to Halls Creek.

Although the Burindi Group is not developed to any extent south of Halls Creek, it is possible that it occurs in places, immediately west of the main fracture of the Peel Fault System. A rich Polyzoan fauna has been found two hundred yards west of the magnesite quarry, approximately half a mile north of Attunga Creek. Abundant fenestrellinids are present, indicative of a Carboniferous or Permian age. It is not possible to represent these occurrences on the accompanying map since they are small in area and their boundaries cannot be delineated accurately.

Alluvial Deposits

Considerable portions of the area are covered by thick alluvium, parts of which date back to the Pleistocene (Brown, 1942, p. 167). Brown states that the Pleistocene alluvials contain

remains of extinct marsupials such as *Diprotodon australis* Owen.

Structural Geology

The area embraces portions of several of the structural elements proposed by Voisey (1959a) in his classification of tectonic elements in New England. These are the *Western Belt of Folds and Thrusts*, the *Great Serpentine Belt*, the *Central Complex* and the *New England Granite Batholith*.

Benson (1917a, p. 228) subdivided the area north of the Namoi River into a number of zones, each characterized by a fairly uniform tectonic structure. Voisey (1958b, p. 212) used these tectonic divisions in describing the Manilla Syncline and associated structures. In this study south of the Namoi River, the terms proposed by Voisey (1959a) are used with various portions of the *Western Belt of Folds and Thrusts* referred to the Yarramanbully Anticline, the Mandowa Syncline and the Klori Anticline.

The New England Batholith

The accompanying map shows the western margins of two adamellite intrusions which are portion of the *New England Granite Batholith*. These intrusions are here named the Attunga Creek Adamellite and Moonbi Adamellite, the term adamellite being used in the sense of Johannsen (1932, p. 309). The Moonbi Adamellite was formerly the Moonbi Granite of Benson (1913c, p. 696; 1915, pp. 586-589; 1917b, p. 606), described by Andrews, Mingaye and Card (1907, pp. 205, 210) as a sphene-diorite-porphyry. These authors were dealing with the extensions of the mass to the east and south. The Attunga Creek Adamellite has not previously been recognized. Both intrusions bear no relation to the structures of the adjacent rocks, for example, the Moonbi Adamellite cuts across the Peel Fault System and the associated serpentinite, thus transgressing the marked structural break between the *Central Complex* and the *Western Belt of Folds and Thrusts*. Considering the intrusions as a tectonic unit, they are post-tectonic types, late members of the Granite Series, that is intrusive magmatic granites or granite plutons in the sense of Read (1955, p. 410). They are surrounded by narrow, well-defined contact aureoles and are excellent examples of "disharmonious" granites as defined by Walton (1955).

The Central Complex

The region from the margins of the batholith to the Peel Fault System is occupied by the

Woolomin Beds. These form portion of the *Central Complex* of New England. Voisey (1958b, p. 212) referred to the Eastern Zone north of Halls Creek, describing it as invariably tightly folded and shattered and having experienced slight dynamic metamorphism. The beds are vertical or dip steeply to the east. The structural complexity of the *Central Complex* has prevented detailed structural study. This extensive deformation marks the zone off as a distinct structural element and this is the most important feature in the present study.

The Great Serpentine Belt

The term serpentinite line was used by Benson (1913a, p. 494) for the "marked line of fault" dividing the region from Warialda to Nundle into two sharply distinguished portions, the Eastern Zone to the east and the less-deformed rocks to the west, which he studied in greater detail. Later (1917a, p. 233), he used this term for one of the zones which he employed in his discussion of the regional geology of the Western Slopes of New England. Voisey (1958b, p. 212) used this term and later (1959, pp. 194-195) the name *Great Serpentine Belt* in his tectonic subdivision of north-eastern New South Wales.

The line of fault marked by the serpentinite was named the Peel Thrust by Carey and Browne (1938, p. 604). Voisey (1958b, p. 212), in referring to the Peel Thrust, remarked that some lateral as well as vertical movements were involved. There can be little doubt that a transverse component was involved in producing the fault although the divergence from a straight line north of Attunga Creek presents a problem in this connexion. Thus the non-genetic term Peel Fault would be preferable to the earlier name. Voisey (1958b, p. 212) stated that the Peel Fault is a complex system of faults, the serpentinite occurring in a number of these. Crook (1961a, p. 173) proposed the name Peel Fault System and he mapped several distinct faults in this System.

Within the Peel Fault System, the junction between highly deformed and less deformed rocks is quite marked and thus most of the tectonic movement took place along a single fracture. This is the fracture shown as the Peel Fault on the accompanying map.

Benson (1917a; 1917b, p. 694) indicated the position of the Serpentine Line south of the Namoi River on his geological maps although this part was not mapped in detail. Detailed mapping has shown that nowhere between Halls Creek and The Horse Arm Creek does the

serpentinite occupy a position in the main fracture of the Peel Fault System. It invariably occurs within the Woolomin Beds to the east. Two large masses occur and there are numerous smaller bodies, many of which could not be shown on the accompanying map.

Benson (1913*a*, p. 494) recorded that the serpentine forms a row of intrusions in the marked line of fault separating the Woolomin Series from the western rocks. He stated that it also occurs to the east of this line and concluded that the great fault plane was the main channel of ascent of the ultrabasic magma. He ascribed the many occurrences to the east to the intrusion along the many fault planes in the shattered eastern block and the few subsidiary intrusions west of the main line to intrusion along subsidiary fault-planes, "such as would be expected to occur here and there by the main great overthrust" (p. 495). Later (1915, p. 585) he reasserted that the serpentine follows the line of fault and he also referred to the use of a small mass to trace the fault line. In his study north of the Namoi River, Benson (1917*a*, p. 233) stated that the fault line is generally occupied by a band of serpentine of varying width and subsequently (1926, p. 39), that the serpentine, from Port Stephens to Warialda, generally occupies a well-marked structure-plain separating highly crushed from less crushed rocks.

In the belt from the Namoi River to The Horse Arm Creek, the serpentinite is absent from the main fracture of the Peel Fault System. A close examination of the Peel Fault System to the north and south would be necessary before this could be stated as a general rule.

The constant relationship between the major fracture of the System and the serpentinite in a belt a few miles to the east implies a genetic connexion. However, it cannot be assumed that the intrusion took place along this fracture, but rather along subsidiary faults. It follows that intrusion could only occur in places with a suitable system of subsidiary faults. This may be the explanation for the discontinuous and irregular outcrops of the ultrabasic rock.

The Yarramanbully Anticline

Benson (1917*a*, pp. 238-239) recorded an anticlinal structure north of the Namoi River in the region occupied by the Tamworth Series on his geological map. Voisey (1958*b*, p. 210) proposed the name Yarramanbully Anticline for this structure. He showed that it continues for a distance of eight miles north of the Namoi River. In this study the Yarramanbully Anti-

cline is recognized as the major structural feature for a considerable distance south of this river. It is a portion of the *Western Belt of Folds and Thrusts*. The anticline is a complex structural feature in which major faulting followed the initial folding. The axial portion and the two limbs form distinct units separated by the important Namoi and Attunga faults.

The eastern limb of the anticline is bounded by the Peel Fault System to the east and the Namoi Fault to the west. The strata, which belong to the Baldwin Formation, invariably dip towards the east at angles of 70 degrees or more. Voisey (1959*b*, p. 212) discussed the general features to the north but did not consider this a portion of the Yarramanbully Anticline. His determination of the anticline was based on strata of the Baldwin Formation north of Halls Creek, to the west of the Namoi Fault, dipping in an easterly direction. The present author considers that a study of the complete structure indicates that these are better regarded as part of the eastern half of the axial portion.

The eastern limb continues to the south in the manner indicated until it is crossed by a fault along Spring Creek. Between Spring and Attunga creeks, the Tamworth Group is represented, the attitude of the beds being unknown. To the south, these are faulted against the rocks of the Tamworth Group and the Baldwin Formation, which pass upwards stratigraphically from east to west. These are intruded to the south by the Moonbi Adamellite.

The Namoi Fault has been recognized by Voisey (1958*b*, pp. 210, 212), who followed it for several miles northward and stated (p. 212) that it undoubtedly continues for a considerable distance to the south. This continuation has now been mapped until the fault is transected by the Moonbi Adamellite on The Horse Arm Creek. The fault must have been at least fifty miles in length before the intrusion of the adamellite, and it warrants recognition as a major structural feature.

Voisey (1959*a*) has shown the Namoi Fault on his tectonic map of north-eastern New South Wales in which it runs into the *New England Granite Batholith* north of Tamworth. He has extrapolated from his studies north of the Namoi River and this has been verified by the present study.

It has not been possible to measure the dip of the Namoi Fault, but as it runs in almost a straight line and appears to have a high dip, it may be a transcurrent fault.

The structures within the axial portion of the Yarramanbully Anticline are most complex. The anticlinal structure within it can be distinguished only in the northern portions, as, for example, in the anticlinally folded limestone on Yarramanbully Creek; to the south the structure is possibly synclinal and it is necessary to consider it in relation to the younger strata dipping away on either side to the east and west. The Yarramanbully Creek limestone plunges slightly to the north and is overlain by cherts of the Tamworth Group. These rocks are faulted against the Baldwin Formation to the north.

There is little sign of the structure south of the limestone on Yarramanbully Creek. Brown (1942, p. 173) indicated a synclinal structure on section C-C between Sulcor and Yarramanbully Road. This interpretation may be correct but it is necessarily based on little evidence as there is a thick cover of alluvium between the limestones on either side. In other places, extensive faulting in the axial portion of the Yarramanbully Anticline has produced numerous fault-bound bodies of limestone within the cherts.

The prevalence of basin structures in some of the limestone bodies in the vicinity of Attunga is worthy of comment. Included among these are the occurrence south of the Inlet Road described by Benson (1917*b*, p. 697), the limestone behind the Burdekin Homestead east of Attunga and that of the Sulcorian Stage on the western side of Attunga Creek one and a half miles north of Attunga.

It is considered that the evidence now available indicates that a fault separates the axial portion of the Yarramanbully Anticline from the Manilla Group to the west, herein named the Attunga Fault. Benson (1917*b*, p. 700) stated that there is no reason for assuming, from the absence of Baldwin Agglomerates, the presence of a fault separating the Middle and Upper Devonian beds at Attunga. He based this on the fact that his studies in the southern part of the Tamworth district had shown that the passage from Middle to Upper Devonian beds was not always marked, as he had formerly believed, by the presence of an intervening mass of Baldwin Agglomerates. He thus assumed that the relationship between the Tamworth Group on the east of the Attunga-Manilla Road and the Manilla Group to the west is an unconformable one in which the Baldwin Formation is absent. Brown (1942, p. 174) states that the field evidence north of Attunga strongly suggests an angular unconformity between the Tamworth Series and the Upper Devonian Barraba Series, outcropping to the west. It has now been

found that in other places where the Tamworth Group is not faulted against the Manilla Group, the sequence is conformable and the Baldwin Formation is always developed. The sequences in which Benson considered that this does not hold have now been shown to be faulted. This is strong evidence that a fault is present and this conclusion is in keeping with the general tectonic picture of the area which has become clearer, owing to the large amount of work undertaken in Western New England, since the Attunga district was studied by Brown.

The Attunga Fault commences to the south near the Tamworth-Attunga Road and follows this north-west to Sulcor. It then swings in a northerly direction which is in direct contrast with the linear nature of the Peel and Namoi faults. This indicates that the fault is a thrust.

The western limb of the Yarramanbully Anticline is located to the west of the Attunga Fault south of Yarramanbully Creek, north of which it is not faulted off from the axial portion. The Tamworth Group has been thrust over all but the upper portions of the Baldwin Formation. The latter dips to the west, generally at low angles, of the order of 10 to 20 degrees. The western limb corresponds with the eastern limb of the Mandowa Syncline in the region immediately south of the Namoi River and this structure will be discussed below.

North of the Namoi River the western limb of the Yarramanbully Anticline corresponds with the eastern limb of the Manilla Syncline. The accompanying map shows the structural features of the southern end of the Manilla Syncline, the information being taken from that of Voisey (1958*b*, Plate VI). The Veness Fault has caused a slight departure from the simple relationship between the two major structures.

The Mandowa Syncline and Klori Anticline

The Mandowa Syncline and Klori Anticline are here recognized as distinct structural features. They occupy the region between the Namoi and Peel rivers and the Attunga-Manilla Road and the northerly extension of the Werrie Basin of Carey (1934). The Klori Anticline also continues for some distance north of the Namoi River.

South of the Namoi River, the western limb of the Yarramanbully Anticline corresponds with the eastern limb of the Mandowa Syncline. The axial portion of the syncline consists of near-horizontal Mandowa Mudstone with the Baldwin Formation to either side. It is faulted to the north against the western limb of the



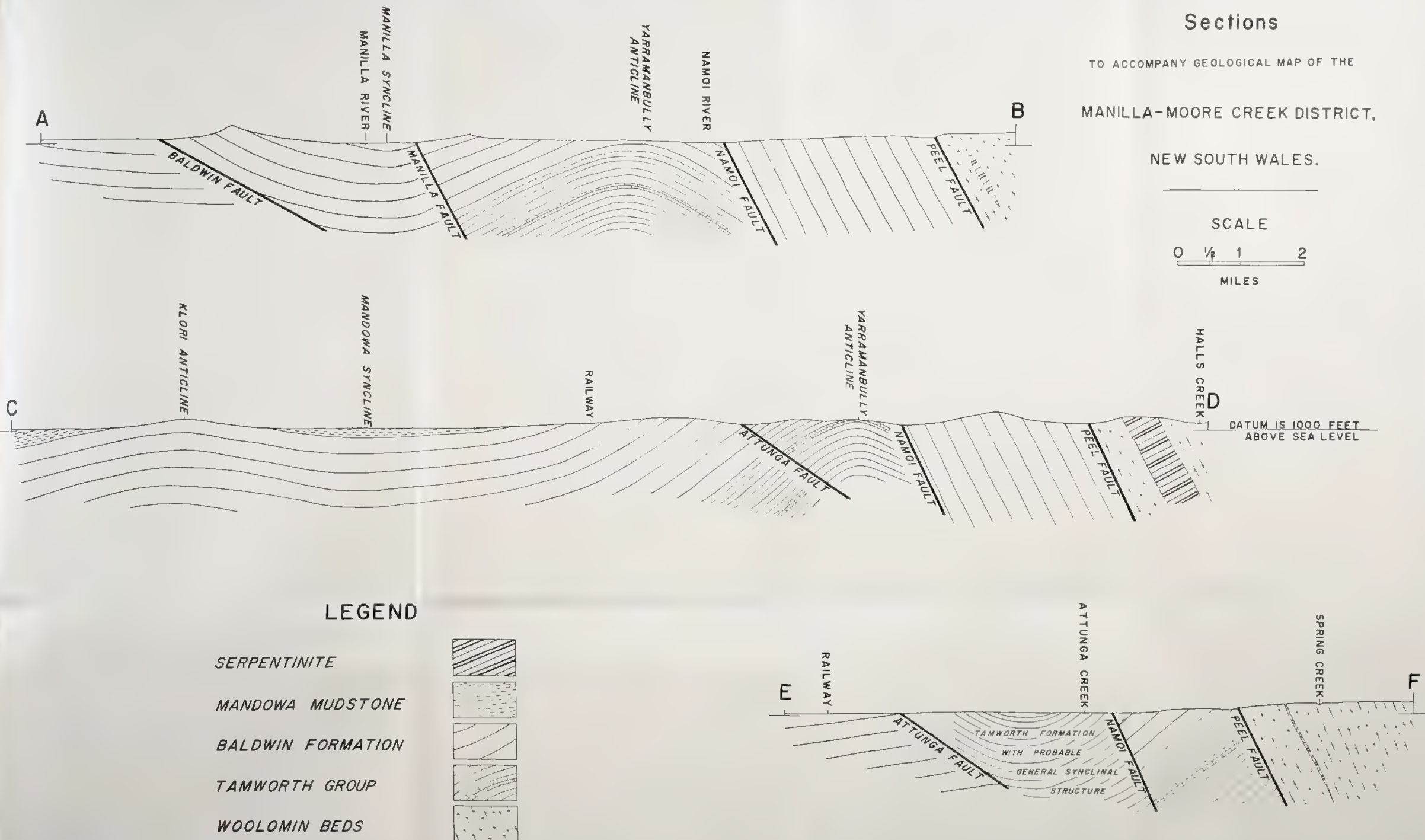


Sections

TO ACCOMPANY GEOLOGICAL MAP OF THE
MANILLA-MOORE CREEK DISTRICT,
NEW SOUTH WALES.



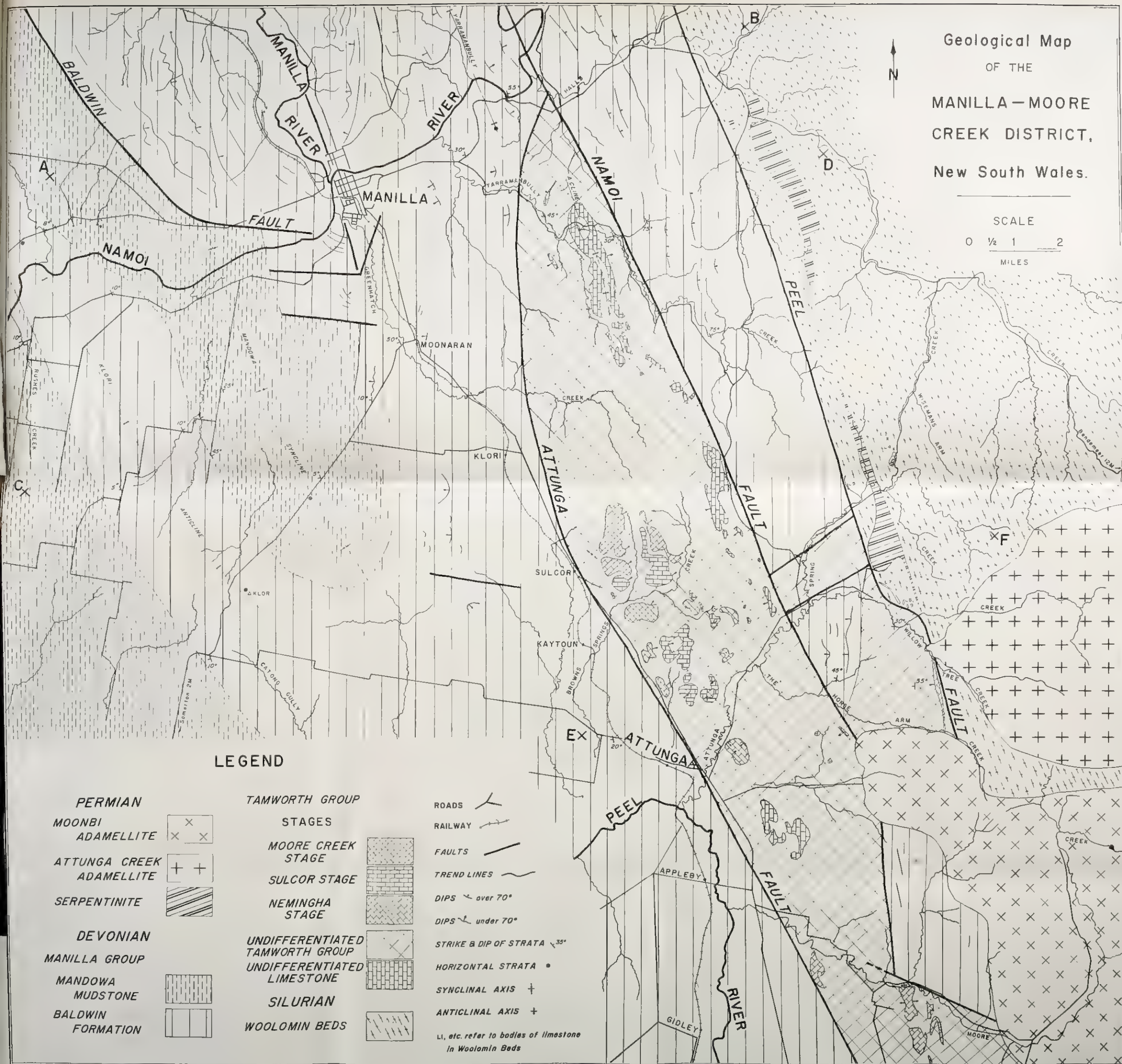
DATUM IS 1000 FEET
ABOVE SEA LEVEL





Geological Map
OF THE
MANILLA—MOORE
CREEK DISTRICT,
New South Wales.

SCALE
0 1/2 1 2
MILES



LEGEND

PERMIAN	
MOONBI	x
ADAMELLITE	x x
ATTUNGA CREEK	+
ADAMELLITE	+
SERPENTINITE	|||||
DEVONIAN	
MANILLA GROUP	
MANDOWA	|||||
MUDSTONE	|||||
BALDWIN	|||||
FORMATION	|||||

TAMWORTH GROUP	
STAGES	
MOORE CREEK	|||||
STAGE	|||||
SULCOR	|||||
STAGE	|||||
NEMINGHA	|||||
STAGE	|||||
UNDIFFERENTIATED	|||||
TAMWORTH GROUP	|||||
UNDIFFERENTIATED	|||||
LIMESTONE	|||||
SILURIAN	
WOOLOMIN BEDS	|||||

ROADS	—
RAILWAY	—
FAULTS	—
TREND LINES	—
DIPS > over 70°	—
DIPS < under 70°	—
STRIKE & DIP OF STRATA 35°	—
HORIZONTAL STRATA	•
SYNCLINAL AXIS	+
ANTICLINAL AXIS	+
LI, etc. refer to bodies of limestone	
in Woolomin Beds	

Manilla Syncline by the south-eastern portion of the Baldwin Fault which here is dominantly transcurrent. The strata in the Manilla Syncline have moved westward relative to the Mandowa Syncline. This is confirmed by the change in strike from north-south to east-west immediately north of the Baldwin Fault. The Mandowa Syncline plunges slightly to the north and is surrounded at the southern end by the Baldwin Formation.

The Klori Anticline is situated between the Mandowa Syncline and the northerly extension of the synclinal axis running through the Werrie Basin. Its axis, marked by the line of hills running from north of Somerton to the Namoi River east of Rushes Creek, continues north almost to Borah Creek. The hills consist of the uppermost beds of the Baldwin Formation which are horizontal and dip away on either side at low angles. Benson (1917a, p. 255) remarked on a hill of Baldwin Agglomerates occurring west of Spring Creek, to the south of Borah Creek, cut off to the west by a fault. Voisey (1958b, Plate VI) also showed Baldwin Formation faulted against Carboniferous strata to the east. Part at least of these so-called Carboniferous rocks are now considered to belong to the Mandowa Mudstone. The over-all structure is an anticline and faults are not necessary to explain the separation of the Baldwin Formation from the Mandowa Mudstone on either side.

In the south the relationships are more complex. The Baldwin Formation continues as a line of prominent hills east from Klori Trig. Station, apparently exposed because of a slight variation in the low dip, whilst to the north the Mandowa Mudstone is present in the axis of the Mandowa Syncline. The wide alluvial plain of the Peel River prevents a correlation with those structures mapped by Crook (1959) to the south.

Cotton and Walkom (1912, p. 704) recorded a series of anticlines and synclines between Tamworth and Somerton. On their section (p. 707) they show an anticline east of Somerton which may correspond to the Klori Anticline to the north.

Structural Features South of Moore Creek

Benson (1915) indicated the structural features south of Moore Creek. The main feature, continuous to the north, is the westerly dipping Manilla Group in the west. It is thought that the Attunga Fault continues for some distance in separating these from the Tamworth Group to

the east. The limestone of the Moore Creekian Stage south of Moore Creek is folded anticlinally and is faulted against cherts of the Tamworth Group at its northern end, as stated by Brown (1942, p. 169). Detailed correlation of structures between Attunga and Moore creeks is impossible due to the presence of the Moonbi Adamellite in the eastern portion and the very poor outcrops west of this.

Benson (1915) showed the position of faults on his map and sections and they are drawn vertically on the latter. Some of these would be better regarded as low angle thrusts, similar to the faults mapped by him (1917a) north of Manilla and restudied by Voisey (1958b). Low angle thrusts are consistent with the tectonic style of the region, which is a zone of marked lateral compression.

Tectonic Evolution of the Tamworth-Manilla District and its Relation to the Tectonic Evolution of New England

The structural study of the Manilla-Moore Creek district is a contribution to the study of Upper Palaeozoic earth movements in north-eastern New South Wales. Voisey (1958b) demonstrated the presence of over-thrust faulting north of Manilla. This was the first work since the time of Benson on the structural evolution of the near-western margins of New England. Previously it had been assumed that the main relief from Late Palaeozoic orogenic pressure occurred along the Mooki thrust system to the west, mapped by Carey (1934).

Voisey (1959a, p. 194) classified the structures between the *Border Thrusts* and the Peel Fault System as the *Western Belt of Folds and Thrusts*. This is characterized by a series of meridional folds and thrusts. To the folds are now added the Klori Anticline, the Mandowa Syncline and the southern development of the Yarramanbully Anticline. The Attunga Fault is an example of a meridional thrust. Voisey has commented on the increase in intensity of the deformation moving east from the *Border Thrusts* to the *Great Serpentine Belt* as the outstanding feature of the *Belt of Folds and Thrusts*. Studies within the present area support this conclusion; the Klori Anticline and the Mandowa Syncline are simple folds whilst the Yarramanbully Anticline to the east is a complex structure, in which much more deformation has occurred.

In addition to the major meridional folds and faults, other features are indicative of intense deformation. The multiplicity of outcrops of limestone between the Attunga and Namoi

faults is indicative of much transcurrent and thrust faulting. There is no reason to suppose that the extensive fracturing shown by the limestone differs from that in other parts of the region east of the Attunga Fault in which distinct horizons are not present.

In the early stages of the compression the area to the north of Manilla was thrown into a number of folds and this also appears to have been the case to the south. The Yarramanbully Anticline and the Manilla Syncline were very likely developed contemporaneously because of the very simple relation between them. The Mandowa Syncline and the Klari Anticline may have been formed at this stage, or alternatively, at a later stage during the development of the Attunga Fault. Increase in the intensity of the orogenic forces produced tighter folding and strike faulting in the region of the Manilla Syncline and the Yarramanbully Anticline. Finally, major fracturing occurred, accompanied by differential movements of the northern portions relative to the southern parts, with development of high angle transcurrent faults.

The Baldwin Fault developed at an early stage in the compression since the folding in the Manilla Syncline produced little effect in the region of the Mandowa Syncline. Movement along this fault became more marked during the later stages as the western limb of the Manilla Syncline was thrust over portion of the eastern limb of the Klari Anticline.

The structures associated with the Peel Fault System formed at an earlier stage in the orogenic history.

Following the compression, the *New England Granite Batholith*, a post-tectonic type, was intruded and this has stabilized the area since the end of the Permian Period.

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The Geology of the Gresford District, N.S.W.

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ABSTRACT—The Lower Carboniferous sequence in the Gresford district is divided into the following formations in ascending stratigraphic order: Bingleburra Formation (mudstone with some limestone and sandstone), Ararat Formation (mainly sandstone), Bonnington Formation (siltstone and mudstone), Flagstaff Sandstone, Wallaringa Formation (sandstone and conglomerate), and Gilmore Volcanics. The Flagstaff Sandstone is approximately the marine equivalent of the non-marine Wallaringa Formation and Gilmore Volcanics. Faunal lists are included, and the ages of the faunas briefly considered. The palaeogeography of the area is discussed. Four new elements in the structure of the area have been recognized. These are Lewinsbrook Syncline, Ararat Basin, Colstoun Basin, and Gresford Basin. The origin of these structures is considered in the light of present structural knowledge of the Hunter Valley Province.

Introduction

The scope of this paper is a study of the geology of Carboniferous rocks in the Gresford district, N.S.W. The area, approximately 30 miles north of Maitland, consists of a Lower Carboniferous sedimentary sequence which has suffered considerable folding and faulting. A number of important facies changes have been observed in the sequence. Only one minor outlier of Tertiary basalt remains from the previously extensive basalt sheet which covered the area.

All map references, unless otherwise specified, are to the Dungog One-Mile Military Sheet. Locality numbers refer to fossil localities, University of New England Collection.

Previous Literature

The first geological investigations in the Gresford district were made by the Rev. W. B. Clarke in 1855, who sent collections of fossils to Europe for identification. The fossils were later described by de Koninck (1876).

Osborne (1950) presented structural and stratigraphical details on the Hunter-Manning-Myll Province of New South Wales, but gave only brief consideration to the area around Gresford.

A comprehensive summary of Carboniferous stratigraphic literature is given by Voisey (1957). References relevant to the Gresford district include: Sussmilch and David (1919), Osborne (1922, 1949), Carey and Browne (1938), Voisey (1945, 1957), and Crockford (1947). Changes in nomenclature for the Carboniferous are tabulated by Voisey (1957, p. 177, Table D).

Stratigraphy

Lower Carboniferous sediments in the Gresford district which accumulated in the New England

Eugeosyncline (Voisey, 1959*b*) have previously been divided into the Kuttung and Burindi Series (Osborne, 1922). Voisey (1959*b*, p. 176) notes that since these names have been used as rock and time-rock terms, as well as for facies variations, they are unacceptable as rock terms as defined by the Australian stratigraphic code.

In this work the sedimentary sequence has been divided into formations, following the Australian Code of Stratigraphic Nomenclature (3rd edition). The relations of the new formations with the nomenclature of Osborne (1922) are given in Table 1. Detailed lithologies of the Bingleburra and Ararat Formations are in Figure 1. Faunal lists are incorporated in Table 2.

Bingleburra Formation

Name—The Bingleburra Formation is named after "Bingleburra" homestead, 46289931, approximately 4 miles north-east of Gresford.

Type Section—The type section extends from the foot of Almonds Hill, eastwards, in the direction of Lewinsbrook Creek (45909967-46179968). Thickness of the type section is approximately 3,000 ft., with fossiliferous mudstones resting against the Camyr Allyn Fault at the base, and interbedded mudstone and siltstone at the top of the formation. The section is conformably overlain by the Ararat Formation. Its importance palaeontologically does not rank with the Lewinsbrook-Trevallyn section (text-fig. 1).

Lithology—The Bingleburra Formation comprises a major mudstone unit containing sandstones, and thin lenses of oolitic and crinoidal limestones. Mudstones are dark brown, and occasionally fossiliferous, while siltstones which become dominant towards the top of the formation are thinly bedded, and exhibit

OSBORNE 1922		GRESFORD DISTRICT	
		Southern Area	Northern Area
KUTTUNG SERIES	Glacial Stage	Glacial Stage	-?-?-?-
		Mt. Johnstone Beds	Flagstaff Sandstone
	Volcanic Stage	Gilmore Volcanics	
	Basal Stage	Wallarunga Formation	Bonnington Fm.
BURINDI SERIES	Burindi	Ararat Formation	Ararat Formation
	Series	Bingleburra Formation	Bingleburra Formation



Marine Formations



Non Marine Formations.

Table I.

sedimentary structures, including cross stratification, washouts, and load casts. Oolitic limestones are cross bedded and lensoidal. Well washed crinoidal limestone lenses are cemented by a coarsely crystalline calcite cement. Fine grained tuffaceous sandstones become coarser and more lithic towards the top of the formation. In the sandstones grains are sub-angular, and well sorted; plagioclase feldspar is oligoclase-andesine, Ab_7An_3 ; and quartz frequently exhibits irregular extinction. Rock fragments include rafted mud fragments, and volcanic fragments. The latter include andesites and dacites of varying types; spherulitic volcanic glass, and microcrystalline lavas. The cement is dominantly calcite, with minor chlorite.

Regional Variation — Gresford-Bingleburra Road Section: A smaller, but more accessible section, approximately 1,000 ft. thick, crops out on the Gresford-Bingleburra road (45939934-46259930). Brown mudstones containing one crinoidal limestone lens underlie a sandstone and conglomerate unit. This passes into mudstones which lie immediately below oolitic limestone lens "a", of the Ararat Formation.

Mt. Richardson Section: Excellent exposures of the Bingleburra Formation occur from 46559935, on the road to Mt. Richardson, to the top of the Wallarobba Range. This section, approximately 2,500 ft. thick, contains fewer limestone lenses, and thinner sandstone units than the type section.

Lewinsbrook-Trevallyn Section: At least seven important fossil horizons are present in this 2,700-foot section located in a westerly dipping fault block. It belongs to a different sedimentary facies from the type section, and with the exception of one oolitic limestone at Lewinsbrook, limestones are absent. Four massive conglomerate lenses present in the section are here designated as members, and are named as follows, in descending order:

Trevallyn Conglomerate	..	350 ft.
Gresford Conglomerate	..	150 ft.
Glenroy Conglomerate	..	200 ft.
Lewinsbrook Conglomerate	..	270 ft.

The conglomerates contain an average of 85% volcanic, 8% sedimentary, and 6% plutonic fragments. Boulders of 2 ft. in diameter occur, but the average size of pebbles is 2-4 in. in diameter. Coarse tuffaceous sandstones are associated with the conglomerates.

Fauna—The fauna of Bingleburra Formation is dominated by the following forms:

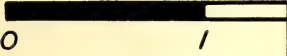
Fistulammina inornata Crockford
Goniocladia laxa (de Koninck)
Schizophoria sp.
Rhipidomella australis (McCoy)
Dictyoclostus sp.
Leptagonia sp.
Asyrinxia lata (McCoy)
Brachythyris sp.

Unispirifer striatoconvolutus (Benson and Dun). The stratigraphic positions of the fossil localities in the Bingleburra Formation are marked on the Lewinsbrook-Trevallyn stratigraphic column, Figure 1. L.65 Lewinsbrook incorporates L.215, L.216, and L.217; L.215 is the lowest horizon.

L.65 Lewinsbrook

Ramipora bifurcata Crockford
Devonoproductus sp.
Krotovia sp.
Spiriferoid n. gen. A
? Delthyris sp.
Balanoconcha sp.
Cleiothyridina 3 spp.
Athyris sp.
Orbiculoidea sp.

SCALE



MILES



BASALT

CARBONIFEROUS

TERTIARY





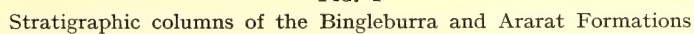


TABLE 2—continued

[illegible]

L.86 Lewinsbrook

Cladochonus tenuicollis (McCoy)

Auloporoid coral

Ramipora sp.*Fenestella* 3 spp.*Lingula* sp.*Orbiculoidea* sp.*Schuchertella* sp.*Streptorhynchus* sp.*Linoproductus* sp.*Pustula* sp.*Devonoproductus* sp.*Phricodothyris* sp.

Spiriferoid n. gen. A

Cleiothyridina 2 spp.*Thomasaria* sp.*Ptychospira* sp.? *Delythris* sp.*Camarotoechia* sp.*Balanoconcha* sp.*Aviculopecten tessellatus* (Phillips)*Aviculopecten* sp.*Streblochondria* sp.*Cyrtosymbole (waribole)* sp.

L.50 Gresford Quarry (including L.218)

Cladochonus tenuicollis (McCoy)*Platycrinites* sp.*Schuchertella* sp.? *Devonoproductus* sp.

Spiriferoid n. gen. A

Cleiothyridina sp.

L.203 Hill above Gresford Quarry (Antiquatonia horizon)

Schuchertella sp.*Phricodothyris* sp.*Antiquatonia* sp.*Syringothyris* sp.*Euomphalus* sp.*Onthonychia* sp.

Trevallyn L.207, L.208, L.233

Prolecanites sp.*Fenestella* sp.*Ramipora bifurcata* Crockford? *Sochkineophyllum* sp.*Lophophylloid* coral*Schuchertella* cf. *pseudoseptata* Campbell*Werria australis* Campbell*Cleiothyridina australis* Maxwell*Phricodothyris* sp.

Spiriferoid n. gen. A

Ptychospira sp.*Krotovia* sp.*Linoproductus* sp.*Camarotoechia* sp.

Rhynchonelloid indet.

Balanoconcha sp.*Aviculopecten tessellatus* (Phillips)*Streblochondria* sp.*Phillipsia* cf. *woodwardi* Etheridge Jr.

Discussion of Geological Age—In the Lewinsbrook-Gresford Quarry collection the following genera are not older than Tournaisian:

*Platycrinites**Cleiothyridina**Goniocladia**Dictyoclostus**Pustula**Linoproductus**Unispirifer**Streptorhynchus**Brachythyris**Phillipsia*

However, the occurrence of *Devonoproductus* and *Thomasaria*, both of which are characteristic of the Upper Devonian overseas, suggests a Lower Tournaisian age for the assemblage.

Devonoproductus occurs in the Upper Devonian of North America in the Independence Shale of Iowa. (Stainbrook, 1943.)

Thomasaria has been found in the Upper Givetian and Frasnian of Belgium (Vander-cammen, 1956); and in the Independence Shale of Iowa (Stainbrook, 1945).

At Trevallyn the goniatite *Prolecanites* occurs with a typical Tournaisian fauna low in the Carboniferous sequence. This age for *Prolecanites* appears to be anomalous, and disagrees with palaeontological and field evidence. *Prolecanites* is known from the Upper Mississippian of U.S.A. (Moore, 1948), and the Middle Viséan of Europe and the Middle East (Delépine, 1941).

Regional Correlation—The Bingleburra Formation can probably be correlated with the lower portions of the Burindi Mudstones, Merlewood Section, Werrie Basin (Carey, 1937).

Ararat Formation

Name—The name is derived from Mt. Ararat, 5½ miles south-east of Gresford.

Type Section—The type section extends from 46179968–46279968, along Lewinsbrook Creek, on the western limb of Lewinsbrook Syncline and has a thickness of 1,500 ft. The base of the Ararat Formation is taken as the base of oolitic limestone lens "a". This unit lenses towards the north, and is not represented in the type section. The top of the formation is the top of oolitic limestone lens "c".

Lithology—The formation in the type section is composed of three sedimentary units which to date are unmappable away from Lewinsbrook syncline. A basal fine grained sandstone unit approximately 400 ft. thick is often quite thinly bedded in units of 2–4 ft., and has no sedimentary structures. This is overlain by approximately

500 ft. of dark brown fossiliferous mudstones with bedding approximately 1 ft. thick, and 550 ft. of coarser grained sandstone with beds always greater than 6 ft. thick which become cross stratified towards the top. This unit is an excellent cliff former.

Minor elements in the formation are oolitic limestone lenses a, b, c, and one crinoidal limestone lens.

Fine grained tuffaceous sandstones in the lower unit become more lithic in the upper division of the formation. Grainsize ranges from 0.5 mm. in the lower unit to 5 mm. in the upper unit, the grains being sub-angular to sub-rounded, and well sorted. Plagioclase feldspar is oligoclase-andesine Ab_7An_3 . Quartz is minor. Rock fragments are entirely volcanics; andesitic and dacitic fragments ranging from coarsely crystalline forms to trachytic types. Moderate amounts of volcanic glasses also occur. The cement is calcite and chlorite. All sandstones, with the exceptions of occasional calcareous sandstones, have a grey-green colour, and weather to a buff shade. Calcareous sandstones which are pale blue when fresh, and weather to a black colour, frequently contain oolite grains, and are cemented by a coarsely crystalline calcite cement.

Oolitic limestones are impure, with feldspar, quartz and rock fragments forming the nuclei of the oolite grains.

Regional Variations—Lewinsbrook Syncline-Mt. Ararat: Rocks of the Ararat Formation crop out along the axis of Lewinsbrook Syncline, from Bingleburra to Mt. Ararat. The steep western scarp of Mt. Ararat is formed by the upper sandstone unit of the Ararat Formation. At the top of the scarp these sandstones are conformably overlain by coarse red zeolitic sandstones belonging to the Wallaringa Formation. The boundary between the two formations is obscured by a basalt residual covering the top of the mountain.

Eastern Limb, Lewinsbrook Syncline: Oolitic limestone lenses "a" and "b" are absent from this section.

Greenhills: A thin sequence of fossiliferous siltstones and sandstones, containing a lens of impure limestone, is present on the crest of Hildale anticline. The sequence is most probably a facies variation in the upper sandstone unit of the Ararat Formation. Faulting obscures its relationship to the underlying sediments.

Fauna—The Greenhills fauna probably has approximately the same age as the fauna present at the base of the Bonnington Formation.

Polyzoa from L.53 are taken from Crockford (1951).

L.53 Greenhills

Fistulipora mirari Crockford
Fistulammina inornata Crockford
Goniocladia laxa (de Koninck)
Fenestella propinqua de Koninck
Fenestella acarinata (Crockford)
Hemitrypa clarkei Crockford
Streblotrypa parallella Crockford
 Lophophylloid coral
Schuchertella sp.
Werrieca sp.
Schizophoria sp.
Rhipidomella australis (McCoy)
Dictyoclostus simplex Campbell
Dictyoclostus paradoxus Campbell
Waagenoconcha delicatula Campbell
Leptagonia sp.
Unispirifer striatoconvolutus (Benson and Dun)
 ? *Pseudosyrinx exuperans* (de Koninck)
Asyrinxia lata (McCoy)
Brachythyris davidis Maxwell
Phricodothyris sp.
Cleiothyridina australis Maxwell
Streptorhynchus sp.
Camarotoechia sp.
Balanoconcha sp.
Aviculopecten ptychotis (McCoy)
Aviculopecten sp.
Euomphalus sp.
Platyceras sp.
Tentaculites sp.
Michelinoceras sp.
Phillipsia cf. *dungogensis* Mitchell.

Age and Correlation—After comparing bryozoa from Greenhills and Glen William with overseas species Crockford (1951) reached the conclusion that their age was equivalent to the Osage Series of U.S.A., and, consequently, with the Upper Tournaisian. Campbell (1957) notes that the faunas from Greenhills and Babbinsboon are very similar. A comparison of the brachiopods from Babbinsboon with overseas material suggests an Upper Tournaisian age.

On this evidence it is fairly certain that the age of the Greenhills fauna is Upper Tournaisian.

Bonnington Formation

Name—The Bonnington Formation is named after the property "Lower Bonnington", approximately 10 miles north-east of Gresford.

Type Section—This section lies immediately above the type section of the Ararat Formation, along Lewinsbrook Creek, 46289970, and has a

thickness of approximately 400 ft. The basal beds of the Bonnington Formation overlie oolitic limestone lens "c" of the Ararat Formation, while the top of the formation is conformably overlain by massive Flagstaff Sandstones.

Lithology—At the base of the formation hard, grey, fossiliferous siltstones in beds 9 in.–1 ft. thick overlie oolite "c". They are fine grained, grainsize being less than 0.2 mm.; grains are angular and are set in a fine feldspathic and chloritic groundmass. The siltstones pass upwards into dense black cherty mudstones, containing occasional beds of soft brown mudstones.

Regional Variation—The Bonnington Formation is known only from Lewinsbrook Syncline.

Fauna—Two fossil localities, L.204 and L.206, occur on one horizon at the base of the formation.

L.204, L.206 Lewinsbrook Syncline

Fenestella sp.

Cladochonus tenuicollis (McCoy)

Lophophylloid coral

Schuchertella sp.

Schizophoria sp.

Rhipidomella australis (McCoy)

Dictyoclostus simplex Campbell

Leptagonia sp.

Unispirifer striatoconvolutus (Benson and Dun)

Asyrinxia lata (McCoy)

Ptychospira sp.

Phricodothyris sp.

Brachythyris sp.

Camarotoechia sp.

Cleiothyridina australis Maxwell

Platycrinites sp.

Phillipsia cf. *dungogensis* Mitchell.

Age and Correlation—This fauna is approximately equivalent to the Greenhills fauna and has an Upper Tournaisian age.

Flagstaff Sandstone

Name—The name is derived from Flagstaff Hill, 1,833 ft., 46121004.

Type Section—The type section of Flagstaff Sandstone extending from 46289970–46431015, north-east along an unnamed tributary of Lewinsbrook Creek, has a thickness of 5,500+ ft. The basal beds conformably overlie mudstones of the Bonnington Formation, and the highest known bed lies against the northern continuation of Lewinsbrook Fault.

Lithology—The Flagstaff Sandstone consists of dark green tuffaceous sandstones, and several very minor developments of grey siltstone, and mudstone. The rocks weather from yellow

to a dark red colour, the latter coloration being due to iron staining. Sandstones range from fine grained labile to coarse, tuffaceous sandstones of a dominantly lithic nature, the latter type constituting the bulk of the formation. Bedding is massive, and has a thickness of greater than 10 ft. Sedimentary structures are absent. Grainsize varies from a minimum of 0.3 mm. in labile sandstones, to a maximum of 2 mm. in tuffaceous sandstones. The grains are angular and sorting is moderate. Plagioclase feldspar is oligoclase-andesine, Ab_7An_3 , at the base of the formation, and becomes slightly more basic in the upper parts of the sequence. Quartz is generally minor. Rock fragments are derived from an andesitic and dacitic volcanic source. Glassy and microcrystalline volcanics are also present. The cement consists of two chlorites, a –ve Penninite; pale green in thin section, showing anomalous blue colours under crossed nicols; optically –ve, with small 2V; pleochroic scheme, X pale green, Y green, Z green; and a magnesium-rich chlorite containing some iron, having a composition of between jenkinsite and delessite; optically negative; birefringence approximately 0.010; usually with a spherulitic habit.

Regional Variation—Colstoun Basin: Flagstaff Sandstones underlie a thin development of the Wallaringa Formation on the southern side of Colstoun, 45449938. In this area the Flagstaff Sandstones are usually cross bedded, indicating a shallowing of the marine basin. South of Colstoun, brown fossiliferous mudstones containing the Dunvegan fossil horizon, L.211, occur 300 ft. below the Martins Creek Andesite.

Fauna—The Dunvegan horizon has approximately the same stratigraphic position as the *Daviesiella aspinosa* horizon, found at Wiragulla, near Dungog, and L.210 Toryburn. Faulting and alluvium obscure stratigraphic relations at the latter locality.

L.210 Toryburn

Schizophoria sp.

Rhipidomella australis (McCoy)

Schuchertella sp.

Leptagonia sp.

Daviesiella aspinosa (Dun)

Dictyoclostus sp.

Pustula cf. *abbotti* Campbell

Unispirifer striatoconvolutus (Benson and Dun)

Aviculopecten tessellatus (Phillips)

Baylea sp.

Euomphalus sp.

L.211 Dunvegan

Caninia sp.
Schizophoria cf. *verulamensis* Cvancara
Rhipidomella sp.
Schuchertella cf. *pseudoseptata* Campbell
Phricodothyris sp.
Brachythyris cf. *pseudovalis* Campbell
Balanocoencha sp.
Euomphalus sp.
Loxonema sp.
Linguaphillipsia cf. *divergens* Cvancara.

Age and Correlation—The following fossils, occurring at the base of the formation, indicate an Upper Tournaisian age for that portion of the sequence :

Daviesiella aspinosa (Dun)
Pustula cf. *abbotti* Campbell
Unispirifer striatoconvolutus (Benson and Dun)
Brachythyris cf. *pseudovalis* Campbell
Schizophorira cf. *verulamensis* Cvancara
Linguaphillipsia cf. *divergens* Cvancara.

Wallingara Formation

Name—The name is taken from "Wallingara" homestead, 47049855 (new locality). The formation is equivalent to the Basal Stage (Osborne, 1922).

Type Section—The section designated as type lies slightly to the east of the region under discussion, and is important in that it shows the transition from marine to non-marine conditions. The type section extends from 47209881–47389888, on the eastern limb of Wallarobba Basin. The base of the formation is approximately 100 ft. below the base of the Wallarobba Conglomerate where coarse red sandstones overlie fine grained marine sediments containing fossiliferous limestone, and calcareous sandstone. The top of the formation is taken as the base of the Martins Creek Andesite. Thickness of the formation is 950 ft.

Lithology—The Wallaringa Formation consists of two sedimentary units, the Wallarobba Conglomerate Member, near the base of the Formation, and a coarse red tuffaceous sandstone sequence.

Wallarobba Conglomerate Member

This unit was first defined by Susmilch and David (1919), and is here designated as a member of the Wallaringa Formation. The Wallarobba Conglomerate is best known from the exposures on the eastern end of Wallarobba Tunnel, North Coast Railway, where it is approximately 350 ft. thick. The maximum

pebble size is 18 in., with an average of 2–4 in. diameter. A pebble sample reveals a higher percentage of sedimentary and plutonic fragments, compared with conglomerates in the Bingleburra Formation.

Volcanic pebbles ..	52%	intermediate volcanics, felsites.
Sedimentary	33%	quartzites, siltstones.
Plutonic	15%	granites, syenites.

Regional Variation—The Wallarobba Conglomerate Member has a variable thickness because of lensing towards the north and north-west. Thin conglomerates occur in the Wallaringa Formation on the western slopes of Mt. Ararat, and west of Gresford, on the Singleton road.

Sandstones.

Tuffaceous sandstones, in beds of more than 6 ft. thick, remain coarse throughout the formation. Sedimentary structures are generally absent. Grain size varies from 0.5–3 mm.; grains are sub-angular to sub-rounded, and are moderately sorted. Quartz is minor, and is often fractured. Plagioclase feldspar is dominantly andesine, Ab_7An_3 . Rock fragments include andesites, dacites and fine grained sedimentary fragments. A minor amount of chlorite is present in the cement. The major cementing mineral is probably stilbite. It is colourless, stained red by iron minerals, has a fibrous and sometimes pseudorhombic habit, and possesses the following optical properties: biaxial negative; $2V$ approximately $30-35^\circ$; low birefringence, 0.008; extinction angle between $0-5^\circ$; N_z is 1.502, ± 0.002 ; X is parallel to the length of elongation.

Regional Variation of the Formation—The Wallaringa Formation is a transgressive, non-marine formation intertonguing in the north with the Flagstaff Sandstone. Thickness of the formation decreases to the north and west. The Wallarobba Conglomerate is not represented north of the town of Gresford, while in the same area zeolitic sandstones underlying the Martins Creek Andesite have a thickness of less than 100 ft.

Because of lack of exposures in the Mt. Ararat-Mt. Brecon area, mapping of the Wallarobba Conglomerate was not attempted.

The Wallaringa Formation overlies the *Daviesiella* fauna at Wiragulla. Since marine fossils are absent from the formation its exact age is unknown.

Gilmore Volcanics

Name—The name is taken from Gilmore Hill, 608 ft., 48329683 (Paterson One-mile Sheet), 2 miles south-east of Clarencetown. This formation is equivalent to the Volcanic Stage (Osborne, 1922).

Type Section—This extends from 48039683–48189675 (Paterson One-mile Sheet), Gilmore Hill. (Also section A–B, Geological Map of the Clarencetown-Paterson District (Osborne, 1922).) Details of the section may be seen in Osborne, 1922, text-fig. 1, and 1949, pp. 296–297. The base of the formation is the base of the Martins Creek Andesite. Ignimbrites, tuffs, and conglomerates in the upper portions of the sequence are conformably overlain by the Mt. Johnstone Beds.

Regional Variation—The extent of regional variation is shown in sections of the Gilmore Volcanics in Sussmilch and David (1919) and Osborne (1922–1949).

Mt. Brecon: No detailed stratigraphy has been undertaken on the Gilmore Volcanics. Fine grained tuffaceous sandstones associated with ignimbrites and lavas in the Mt. Brecon section are mainly labile sandstones. Plagioclase feldspar is generally andesine. Quartz is more abundant than in lower formations, and is frequently rounded. Grainsize ranges from 0.3–1 mm., the grains being well rounded and well sorted. The cement is a colourless zeolite, probably stilbite, stained red by iron minerals. Lavas and ignimbrites which are localized and do not extend far to the north from Mt. Brecon are replaced in the sequence by zeolitic tuffaceous sandstones similar to those in the Wallaringa Formation.

Further south the Gilmore Volcanics are conformably overlain by the following units:

Mt. Johnstone Beds (Sussmilch and David, 1919), approximately 2,000 ft. of sandstone, conglomerates, and localized varve shales. Paterson Toscanite (Osborne, 1922).

Main Glacial Beds (Osborne, 1922), approximately 1,800 ft. of varve shales, tillites, and tuffaceous sandstones.

Sedimentation and Palaeogeography

During the Lower Tournaisian, marine conditions prevailed throughout the Gresford area. Two distinct sedimentary facies were present during the deposition of both the Bingleburra and Ararat Formations.

Bingleburra Formation—In this formation the facies are a shallow water platform area of sedimentation in the north, containing oolitic

and crinoidal limestones, and a clastic environment in the south, with massive marine conglomerates. The two facies intertongue.

Ararat Formation—Increased activity of source area resulted in the deposition of a thick blanket of tuffaceous sandstones. Oolitic and crinoidal limestones were again generally restricted to the platform area in the north. Towards the end of Ararat sedimentation, the sea shallowed in the Hilledale-Mt. Ararat area, forming a small island or peninsula (text-fig. 2A).

During the Upper Tournaisian and at least the lower part of the Visean marine–non-marine environments existed contemporaneously.

Marine Sedimentation

Rapid deposition of sediment occurred in the north-western part of the region, while the eastern basin tended to shallow, and received less detrital material.

Bonnington Formation: This formation overlies the Ararat Formation in the marine area, and appears to be restricted to the north-west of the land area.

Flagstaff Sandstone: The Flagstaff Sandstone, a massive marine sandstone unit occurring to the north and north-west of the land area, intertongues with the Wallaringa Formation in the vicinity of Gresford township. Flagstaff Sandstone sedimentation was entirely marine north of Allynbrook.

Non-Marine Sedimentation

Wallaringa Formation: From the initial emergence it seems likely that sediments began accumulating on the land area, which was for the first part restricted to the small area around Hilledale and Mt. Ararat. Towards the end of the Tournaisian the area of non-marine sedimentation increased in the north, west and east (text-fig. 2B). This increase in area was accompanied by a rise in source lands and the deposition of massive conglomerate lenses, viz., the Wallarobba Conglomerate.

Gilmore Volcanics: The outburst of vulcanism from a number of centres on the land area in the south provided fresh sources of sediment for both marine and non-marine environments. Osborne (1949) lists the following volcanic centres near Gresford: Mt. Brecon, Martins Creek, Glenoak, and Gilmore Hill. Fresh water sandstones are common in the Gilmore Volcanics.

Mt. Johnstone Beds and Glacial Stage: Following the slackening of volcanic activity, non-marine sedimentation continued in the southern area. Glaciation commenced, depositing varves and tillites over a wide area of the non-marine environment.

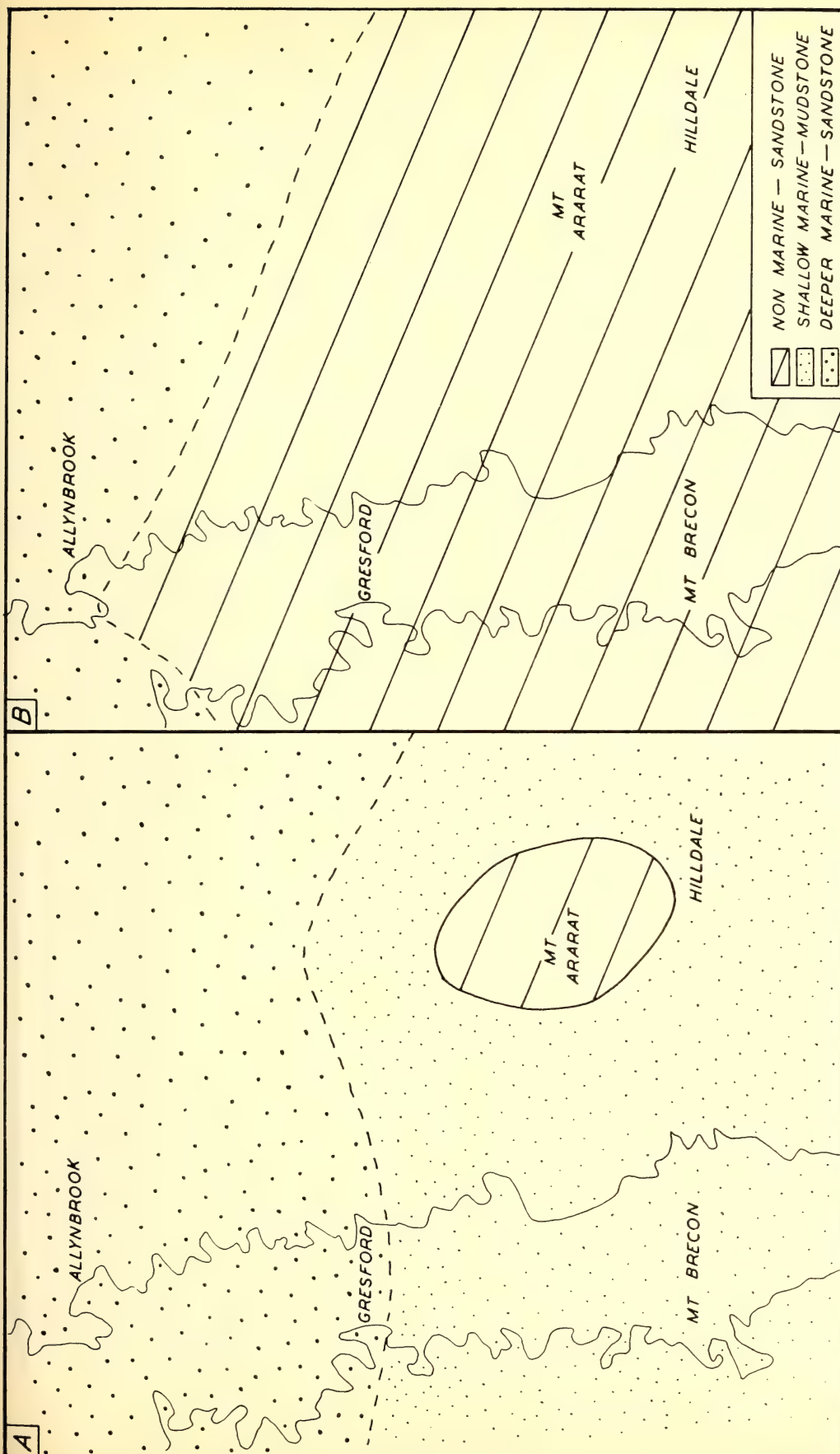


Fig. 2

Palaeogeographic diagrams of the Gresford District

A. Initial emergence at the end of Ararat sedimentation

B. Stage of greatest emergence at the end of Wallaringa sedimentation

The Sandstones

Tuffaceous sandstones are difficult to place in any of the accepted classifications. Using the classification of Packham (1954), all sandstones from the Gresford district fall into the Labile Sandstone field. The mineralogy of the sandstone is as follows.

Plagioclase feldspars from the lower and middle portions of the sequence have an average composition of Ab_7An_3 , oligoclase-andesine. They become slightly more basic towards the top of the Flagstaff Sandstone, where they are andesine.

Quartz is generally minor throughout the sequence, but becomes more abundant in the Gilmore Volcanics. It is typically shattered, and has an uneven extinction. Rock fragments are almost exclusively of volcanic origin, ranging from andesites to dacites in composition. Fine grained microcrystalline volcanics and glasses occur throughout the sequence.

Accessory minerals include biotite, hornblende, iron ore, zircon, and apatite.

Cementing minerals in sandstones provide significant differences in lithology in the various formations in the Gresford District.

Formation

Gilmore Volcanics
Warringa Fm.
Flagstaff Sandstone
Ararat Fm.
Bingleburra Fm.

Cementing Mineral

Colourless zeolite (Stilbite)
" " minor chlorite
Chlorite (negative Penninite, Jenkinsite-Delessite)
Calcite, with minor chlorite
Calcite, with minor chlorite

Since in this area there is no evidence of alteration in the nature of the cements with depth of burial, the composition of cements will depend on the original composition of the rock, and the environment of deposition.

The significance of the cementing minerals becomes apparent when the environment of deposition is considered. Sandstones of the Bingleburra and Ararat Formations, deposited in a calcareous rich marine environment, are cemented by calcite and minor chlorite.

Non-marine conditions, combined with nearby volcanic activity, produced a chemical environment suitable for the formation of a zeolite cement, in the Warringa Formation, and the Gilmore Volcanics. The zeolite cementing mineral does not appear to be due to the depth of burial, but is a localized feature controlled by the chemical environment. Zeolitic rocks intertongue with the Flagstaff Sandstone.

The Flagstaff Sandstone, deposited in the marine environment, synchronously with the Warringa Formation and Gilmore Volcanics,

is cemented by chlorite. The marine environment to the north of Gresford was no longer rich in calcareous organisms, possibly because of the onset of a colder climate, and the increased rate of sedimentation.

The abundance of intermediate volcanic fragments in all sandstones points to an andesitic island arc source area. Voisey (1959b) suggested this type of source area for most of the New England Eugeosyncline during the Devonian and Carboniferous.

Structure

The Gresford District is situated in a complex structural position, at the intersection of north-westerly trending fold axes with the basin belt on the north-eastern margin of the Hunter Thrust and the Stroud-Gloucester Trough. The generalized tectonic position is given by Voisey (1959a, Fig. 1).

Osborne's concept of the Gresford-Wallarobba Anticline has been revised.

The structure contour map was prepared using the height contours on the Dungog One-mile Military Sheet. Zero feet is taken at the top of the Ararat Formation. Datum points

were obtained where this boundary, and other beds at a known stratigraphic distance above or below the top of the Ararat Formation crossed contour lines on the One-mile Sheet. Dotted contours are approximations where datum points were unobtainable.

Folding

Folds trend generally in a north-south direction. Basin structures in the southern portions of the area link up with synclinal axes, at times grading into true synclines towards the north.

Carey and Osborne (1939) suggest that deflected fold axes are due to rotational stress caused by movement on the Hunter Thrust. In this area sigmoidal curvature of fold axes occurs between the basins.

Lewinsbrook Syncline is a closed, plunging, asymmetrical syncline. For presentation of structural details it is divided into the southern area of closure and the northern area.

Southern area of closure : The axial plane has an average dip to the north-west of 55° and strikes at $N 70^\circ E$. The angle between the steep western limb and the axial plane is 65° , while that between the shallowly dipping eastern limb and the axial plane is 35° .

Northern area : The axial plane has twisted from its southern orientation, dips at approximately 60° to the east, and strikes at 360° . The angle between the shallow western limb and the axial plane is 32° , while that between the steep eastern limb and the axial plane is 60° .

The axis plunges northwards at 5° . Lewinsbrook Syncline extends 5 miles north from Bingleburra Homestead before being truncated by Lewinsbrook Fault. To the south the synclinal axis plunges into the Ararat Basin.

The *Ararat Basin* is a shallow structure with an elongate northern closure. All the margins except the northern end are truncated by faults. In the northern area of closure the axial plane has an average dip to the east of 80° , and strikes at 360° . The angle between both the shallow western limb, and the steeper eastern limb, and the axial plane, is 55° .

The central part of the basin is symmetrical, and is surrounded by uniformly dipping limbs. In the northern portion of the basin the axis plunges at approximately 3° to the south.

The *Colstoun and Gresford Basins* are two shallow basins situated on a sigmoidal synclinal axis. The change in plunge between the basins occurs at Gresford township. The Colstoun Basin is a long, narrow, symmetrical basin, closed at both ends, extending from Gresford to Allynbrook. The axial plane is sigmoidally twisted, approximately vertical, and has a general strike of 360° . At the southern closure the axis strikes at 150° . The plunge at either end of the basin is less than 5° . Colstoun Basin is flanked on both sides by shallow anticlinal structures which on present evidence appear to be out of harmony with the major folds in the area. The Gresford Basin is a broader and less well defined structure, all margins except the northern closure being faulted. The axial plane is vertical, strikes at approximately 200° , and plunges to the south at approximately 3° .

The *Wallarobba Basin* has previously been described by Osborne (1950). The western limb is truncated by Hilledale Fault. The axial plane is vertical, the axis having only shallow plunges at either end of the basin. The eastern limb of the synclinal axis, of which the Wallarobba Basin is part, extends almost as far north as Mt. Windeyer, 1,245 ft., 46999985.

The *Hilledale Anticline* is the only major anticlinal structure present in the Gresford area, and is extensively broken by normal and reverse faults. The anticlinal crest is visible at Greenhills, where it plunges slightly to the south-east. This structure was first recognized by Osborne (1922).

Faulting

Major faults in the Gresford district are long strike faults, usually following anticlinal trends. The larger faults are discussed below. Others may be seen on the cross section and the geological and structure contour maps.

Lewinsbrook Fault has been previously mapped, and named by Osborne (1950). It is a steep reverse fault, having a strike of approximately 360° , and an estimated throw of 3,000 ft., just north of Mt. Richardson. The fault plane plunges south.

Camyr Allyn Fault is named after Camyr Allyn bridge, Gresford. The southern portions of the fault branch and are disrupted by numerous smaller fractures in the neighbourhood of Gresford Quarry. The Camyr Allyn fault is a steep reverse fault, striking at essentially 360° , and has a throw varying from 3,500 ft. near Allynbrook, to 600 ft. near Mt. Brecon. The eastern side of the fault is the upthrow side.

Hilledale Fault has previously been mapped in part by Osborne (1950). The author has traced it further to the north, where its strike swings from $N 20^\circ E$ to 360° . Throw in the southern portion is not more than 500 ft. where the eastern side is the down throw side. In the north, the fault has a throw of approximately 1,000 ft.

Structural Evolution

The views of Osborne (1950) regarding the movements in the Hunter-Bowen Orogeny in the Hunter-Manning-Myall province may be summarized as follows :

1. End of Muree, stress from the east commenced the folding of the Stroud-Gloucester Trough, and the Lochinvar Dome.
2. Upper Marine time, this stress is renewed, the above structures becoming major tectonic features.
3. Change in stress direction, with maximum compressive stress from the north-east.
4. Movement on the Hunter Thrust caused rotational stress and the formation of the basin belt.

The structural trends in the Gresford district roughly parallel the Stroud-Gloucester Trough, but north-west of this area there is a tendency for

trends to assume a north-westerly direction. It is suggested that the presence of the Stroud-Gloucester Trough as an active tectonic feature during the Hunter-Bowen Orogeny prevented folds on its margins assuming the normal north-westerly trends impressed upon the area in the major stages of deformation.

Later movements on the Hunter Thrust produced rotational stress forming the basin belt, extending from the southern tip of the Stroud-Gloucester Trough to the Werrie Basin (Voisey, 1959a). The rotational stress may have been responsible for the changes in plunge along synclinal axes, some distance from the thrust, forming narrow elongate basins similar to the Colstoun Basin. The axes of these basins also show a slight sigmoidal curvature.

Faults were also influenced by the presence of the Stroud-Gloucester Trough, which interfered with the maximum stress direction. Major fractures are steep reverse faults, more or less parallel to the trough, usually situated along anticlinal crests.

Fossil Localities

The following localities, listed in stratigraphic order, comprise the major fossil horizons in the Gresford District.

- L.211 Dunvegan, 45109898 Camberwell One-mile Sheet. Dam excavation at the top of a rounded hill south-west of the Paterson River.
- L.210 Toryburn, 45959855. Creek bank immediately behind the house at "Toryburn".
- L.206 Lewinsbrook Syncline, 46279968. Bank of Lewinsbrook Creek 75 yards south of stockyards.
- L.204 Lewinsbrook Syncline, 46409953. Eastern side of the hill forming the nose of Lewinsbrook Syncline; Richardson's farm.
- L.53 Greenhills, 46609790 Paterson One-mile Sheet. Gully one-quarter of a mile north of the Martins Creek-Dungog road.
- L.207 Trevallyn, 45689862 Trevallyn quarry. Gresford-Paterson road.
- L.233 Trevallyn, 45759864. Gully to the north-east of Trevallyn Quarry.
- L.208 Trevallyn, 45759864. Eastern slope of hill one-quarter of a mile north-east of Trevallyn quarry.
- L.203 Antiquatonia horizon, 45989908. Near the head of a gully on the hill half a mile east of Gresford quarry.

- L.218 Gresford Quarry, 45809912. Gully 50 yards to the east of Gresford quarry.
- L.50 Gresford Quarry, 45789913. Lewinsbrook road, one mile north-east of Gresford.
- L.86 Lewinsbrook, 46089885. Gully to the west of the Lewinsbrook-Gresford road approximately half a mile north-east of Lewinsbrook school.
- L.65 Lewinsbrook, 46089882. Includes L.215, L.216, and L.217. South bank of small gully 40 yards east of L.86.

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On a Group of Transforms Containing the Fourier Transforms

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ABSTRACT—The Fourier transforms considered in this paper are those defined by

$$g(x)=(d/dx)\int_0^\infty (k(xy)/y)f(y)dy$$

where the Mellin transform of $k(x)/x$ is $K(s)/(1-s)$ with $K(s)$ bounded on the line $s=\frac{1}{2}+it$.
By adjoining to this set of transforms a set of transforms of the type

$$g(x)=(d/dx)\int_0^\infty (k(y)/y)xf(xy)dy$$

we can form a group.

In this paper, author comments on some of the subgroups which are determined by simple properties of the $k(x)$.

1

The N - transform in L^2 is defined by

(1.1)
$$F(s)=\lim_{\eta\rightarrow\infty}\int_{1/\eta}^\eta x^{s-1}f(x)dx$$
$$=N[f(x)]$$

where $s=\frac{1}{2}+it$ ($-\infty < t < \infty$).

This transform maps functions $f(x)$ belonging to $L^2(0, \infty)$ on to functions $F(s)=F(\frac{1}{2}+it)$ belonging to $L^2(-\infty, \infty)$. The mapping is (1-1) and the inversion formula is

(1.2)
$$f(x)=(2\pi)^{-1}\lim_{\eta\rightarrow\infty}\int_{-\eta}^\eta x^{-s}F(s)ds$$
$$=N^{-1}[F(s)].$$

The N -transform is well-known and sufficient details for our purposes will be found in Titchmarsh (1948), mainly in Chapter VIII. We will write throughout $1-s=\frac{1}{2}-it$.

Now suppose that $K(s)=K(\frac{1}{2}+it)$ and $H(s)=H(\frac{1}{2}+it)$ are measurable and bounded for all t , and that

(1.3)
$$K(s)H(s)=1.$$

For each such $K(s)$ we may define by means of equation (1.2) two functions $k_1(x)/x$ and $k_2(x)/x$ belonging to $L^2(0, \infty)$ so that

(1.4a)
$$N[k_1(x)/x]=K(s)/(1-s)$$

and
(1.4b)
$$N[k_2(x)/x]=K(1-s)/s.$$

Using the functions $k_1(x)$ and $k_2(x)$ we then introduce the transforms

(1.5a)
$$g_1(x)=S_K[f(x)]$$
$$=(d/dx)\int_0^\infty (k_1(xy)/y)f(y)dy$$

and

$$(1.5) \quad \begin{aligned} g_2(x) &= T_K[f(x)] \\ &= (d/dx) \int_0^\infty (k_2(y)/y) x f(xy) dy \end{aligned}$$

where $f(x)$, $g_1(x)$ and $g_2(x)$ belong to $L^2(0, \infty)$.

Applying the N -transform to equations (1.5a) and (1.5b) and using the same transform symbols, we obtain

$$(1.6a) \quad \begin{aligned} G_1(s) &= K(s) F(1-s) \\ &= S_K[F(s)] \end{aligned}$$

and

$$(1.6b) \quad \begin{aligned} G_2(s) &= K(s) F(s) \\ &= T_K[F(s)], \end{aligned}$$

where $G_1(s)$, $G_2(s)$ and $F(s)$ are the N -transforms of $g_1(x)$, $g_2(x)$ and $f(x)$, and as functions of t $G_1(s)$, $G_2(s)$ and $F(s)$ belong to $L^2(-\infty, \infty)$.

Taking equation (1.3) into consideration, it is obvious that the set of all transforms generated in the various $K(s)$ form a group.

The unit transform is easily obtained. In equation (1.4b) write

$$k_2(x) = \begin{cases} x, & 0 < x < 1 \\ \frac{1}{2}, & x = 1 \\ 0, & x > 1 \end{cases}$$

from which $K(s)=1$. That this is the unit transform is verified from equation (1.6b) or directly as follows

$$\begin{aligned} g_2(x) &= (d/dx) \int_0^1 x f(xy) dy \\ &= (d/dx) \int_0^x f(u) du \\ &= f(x). \end{aligned}$$

Now in equation (1.4a) put

$$k_1(x) = \begin{cases} 1, & x > 1 \\ \frac{1}{2}, & x = 1 \\ 0, & x < 1 \end{cases}$$

then $K(s)=1$. The particular transform generated by this $k_1(x)$ we will call A .

Equations (1.6a) and (1.5a) show that

$$(1.7a) \quad A[F(s)] = F(1-s)$$

and

$$(1.7b) \quad \begin{aligned} A[f(x)] &= (d/dx) \int_0^x (1/y) f(y) dy \\ &= (1/x) f(1/x). \end{aligned}$$

With the introduction of the transform A , we note that $T_K = S_K A$ and $S_K = T_K A$.

Suppose now that the S_K transform has been defined for a kernel $k_1(x)$. Then

$$\begin{aligned} T_K[f(x)] &= T_1 A[f(x)] \\ &= (d/dx) \int_0^\infty (y^{-1} k_1(xy)) (y^{-1} f(y^{-1})) dy \\ &= (d/dx) \int_0^\infty k_1(x/y) f(y) dy \\ &= (d/dx) \int_0^\infty k_1(1/y) x f(xy) dy. \end{aligned}$$

Thus

$$(1.8) \quad k_2(x) = x k_1(1/x).$$

2

The S_K -transforms are usually called Fourier type transforms and we may write

$$S_K^{-1} = S_L \text{ where } L(s) = 1/K(1-s)$$

and for the T_K -transforms

$$T_K^{-1} = T_L \text{ where } L(s) = 1/K(s).$$

For all $L(s)$ and $K(s)$,

$$\begin{aligned} (2.1) \quad T_K T_L [F(s)] &= K(s) L(s) F(s) = T_L T_K F(s) \\ (2.2) \quad S_L S_K [F(s)] &= L(s) K(1-s) F(s) \\ (2.3) \quad S_K S_L [F(s)] &= K(s) L(1-s) F(s) \\ S_L T_K [F(s)] &= L(s) K(1-s) F(1-s) \\ T_K S_L [F(s)] &= L(s) K(s) F(1-s). \end{aligned}$$

Equation (2.1) shows that the set of all the T_K form a commutative subgroup G_1 of the group of transforms. The group can be divided into the two cosets G_1 and AG_1 (or G_1A), all the Fourier type transforms will be in the second coset.

The only elements of the group which commute with all elements of group are the T_K -transforms for which $K(s) = K(1-s)$. In addition the set of S_K and T_K with $K(s) = K(1-s)$ form a commutative subgroup.

3

In this section we determine the restrictions placed on $k_1(x)$ and $k_2(x)$ by the equation $K(s) = K(1-s)$.

To facilitate the calculations we notice that Th. 62 of Titchmarsh (1948) shows that due to the restrictions placed on $K(s)$

$$N^{-1}[K(s)/(1-s)] = (2\pi)^{-1} \lim_{\eta \rightarrow \infty} \int_{-\eta}^{\eta} x^{-s} K(s)/(1-s) dt,$$

that is the mean square integral may be replaced by a limit integral.

By the definition

$$(2\pi)x^{-1}k_2(x) = \int_{-\infty}^{\infty} K(\tfrac{1}{2}-it)(\tfrac{1}{2}+it)^{-1}x^{-\frac{1}{2}-it}dt,$$

then by Titchmarsh (1944, Th. 72, p. 95)

$$\begin{aligned} (2\pi) \int_1^x y^{-1}k_2(y)dy &= \int_{-\infty}^{\infty} \frac{K(\tfrac{1}{2}-it)}{(\tfrac{1}{2}+it)(\tfrac{1}{2}-it)} (x^{\frac{1}{2}-it}-1)dt \\ &= \int_{-\infty}^{\infty} K(\tfrac{1}{2}-it)(x^{\frac{1}{2}-it}-1)((\tfrac{1}{2}+it)^{-1}+(\tfrac{1}{2}-it)^{-1})dt \\ &= x \int_{-\infty}^{\infty} K(\tfrac{1}{2}-it)(\tfrac{1}{2}+it)^{-1}x^{-\frac{1}{2}-it}dt \\ &\quad + \int_{-\infty}^{\infty} K(\tfrac{1}{2}+it)(\tfrac{1}{2}+it)^{-1}x^{\frac{1}{2}+it}dt \\ &\quad - \int_{-\infty}^{\infty} K(\tfrac{1}{2}-it)(\tfrac{1}{2}+it)^{-1}dt - \int_{-\infty}^{\infty} K(\tfrac{1}{2}+it)(\tfrac{1}{2}+it)^{-1}dt \end{aligned}$$

(where the second and fourth integrals have been obtained after change of sign of t). Then using $K(\tfrac{1}{2}+it) = K(\tfrac{1}{2}-it)$ we obtain

$$\begin{aligned} (3.1) \quad \int_1^x y^{-1}k_2(y)dy &= x(k_2(x)/x) + k_2(1/x)(1/x) - k(1) - k(1) \\ &= k_2(x) + xk_2(1/x) - 2k_2(1). \end{aligned}$$

In order to verify that if equation (3.1) holds then $K(\frac{1}{2}+it)=K(\frac{1}{2}-it)$, we substitute the defining expressions for each of the terms on right side of (3.1) and use the previously determined expression for $\int_1^x y^{-1}k_2(y)dy$. After collection of terms we obtain

$$\int_{-\infty}^{\infty} \frac{K(\frac{1}{2}+it)-K(\frac{1}{2}-it)}{\frac{1}{2}-it} x^{\frac{1}{2}+it} dt = \int_{-\infty}^{\infty} \frac{K(\frac{1}{2}+it)-K(\frac{1}{2}-it)}{\frac{1}{2}-it} dt \\ = C \text{ (a constant).}$$

Thus

$$\int_{-\infty}^{\infty} \frac{K(\frac{1}{2}+it)-K(\frac{1}{2}-it)}{\frac{1}{2}+it} x^{-\frac{1}{2}-it} dt = -\frac{C}{x}$$

which belongs to $L^2(0, \infty)$ only if $C=0$. This gives the required result.

The $k_1(x)$ of the transform S_k can be treated similarly.

Since

$$(2\pi)x^{-1}k_1(x) = \int_{-\infty}^{\infty} K(\frac{1}{2}+it)(\frac{1}{2}-it)^{-1}x^{-\frac{1}{2}-it} dt, \\ (2\pi)\int_x^{\infty} y^{-2}k_1(y)dy = \int_{-\infty}^{\infty} \frac{K(\frac{1}{2}+it)}{(\frac{1}{2}-it)(\frac{1}{2}-it)} x^{-\frac{1}{2}-it} dt \\ = \int_{-\infty}^{\infty} K(\frac{1}{2}+it)(\frac{1}{2}-it)^{-1}x^{-\frac{1}{2}-it} dt \\ + x^{-1}\int_{-\infty}^{\infty} K(\frac{1}{2}-it)(\frac{1}{2}-it)^{-1}x^{\frac{1}{2}+it} dt.$$

Since $K(\frac{1}{2}+it)=K(\frac{1}{2}-it)$, this may be written as

$$(3.2) \quad \int_x^{\infty} y^{-2}k_1(y)dy = x^{-1}k_1(x) + k(1/x)$$

Equation (3.2) shows that

$$(3.3) \quad \lim_{x \rightarrow \infty} [x^{-1}k_1(x) + k_1(1/x)] = 0$$

and that

$$(3.4) \quad \int_1^x y^{-2}k_1(y)dy = 2k(1) - x^{-1}k_1(x) - k_1(1/x),$$

the last of which corresponds to equation (3.1).

Then using equation (1.8) we may obtain

$$(3.5) \quad \lim_{x \rightarrow \infty} [x^{-1}k_2(x) + k_2(1/x)] = 0.$$

A simple but illustrative example is to take $K(s)=1$, from which we find that

$$k_2(x) = \begin{cases} x, & 0 < x < 1, \\ 0, & x > 1, \end{cases}$$

and

$$k_1(x) = \begin{cases} 0, & 0 < x < 1, \\ 1, & x > 1. \end{cases}$$

At the discontinuity both $k_1(1)$ and $k_2(1)$ must take the mean value $\frac{1}{2}$. By direct calculation

$$\int_1^x y^{-1}k_2(y)dy = \begin{cases} x-1, & 0 < x < 1, \\ 0, & x > 1, \end{cases}$$

and

$$\int_1^x y^{-2}k_1(y)dy = \begin{cases} 1-x^{-1}, & x > 1, \\ 0, & 0 < x < 1. \end{cases}$$

4

Associated with each S_K are two additional transforms AS_K and $AS_KA=AT_K$. The work of the previous sections makes the examination of these transforms rather easy. Firstly

$$AS_K[F(s)]=K(1-s)F(s)$$

and the kernel which generates this transform is given by $k_3(x)/x=N^{-1}[K(s)/s]$.

Rewriting equation (3.2a) after changing the sign of t in the second term on the right side we obtain

$$\int_x^\infty y^{-2}k_1(y)dy=k_1(x)/x+N^{-1}[K(s)/s]$$

that is

$$(4.1) \quad k_3(x)=x \int_x^\infty y^{-2}k_1(y)dy-k_1(x).$$

The transform AT_K is of the S-type for which

$$AT_K[F(s)]=K(1-s)F(1-s).$$

Its kernel $k_4(x)$ is determined from $k_4(x)/x=N^{-1}[K(1-s)/(1-s)]$.

Since we may write AS_KA in the form $(AS_K)A$, we may use equation (1.8). Thus we have after some simplification

$$(4.2) \quad k_4(x)=\int_0^x k_1(1/t)dt-xk_1(1/x).$$

In the case of the "cosine" transform for which $K(s)=\Gamma(s)\cos\frac{1}{2}\pi s$, the associated transforms are

$$S_K: \quad (d/dx) \int_0^\infty y^{-1} \sin xy f(y) dy,$$

$$T_K=S_KA: \quad (d/dx) \int_0^\infty \sin y^{-1} \cdot x f(xy) dy,$$

$$AS_K=AT_KA: \quad (d/dx) \int_0^\infty \left(\int_y^\infty t^{-1} \cos t dt \right) x f(xy) dy,$$

$$AS_KA=AT_K: \quad (d/dx) \int_0^\infty y^{-1} \int_0^{xy} t^{-1} \cos t^{-1} dt \cdot f(y) dy.$$

5

Doetsch (1939) has shown that λ is an eigenvalue of S_K , provided that $\lambda^2=K(s)K(1-s)$ on a set E_K of t of non-zero measure. Using a similar method it is easy to show that λ is an eigenvalue of T_K if $\lambda=K(s)$ on a set E'_K of t of non-zero measure. We may call the sets E_K and E'_K , carrier sets of the eigenvalues.

Now

$$(5.1a) \quad T_L^{-1}S_KT_L[F(s)]=K(s)L(1-s)/L(s) \cdot F(1-s) \\ =S_M[F(s)],$$

$$(5.1b) \quad S_L^{-1}S_KS_L[F(s)]=K(1-s)L(s)/L(1-s) \cdot F(1-s) \\ =S_n[F(s)],$$

$$(5.2a) \quad T_L^{-1}T_KT_L=T_K,$$

$$(5.2b) \quad S_L^{-1}T_KS_L[F(s)]=K(1-s)F(s) \\ =T_P[F(s)],$$

where obviously $M(s)M(1-s)=N(s)N(1-s)=P(s)P(1-s)=K(s)K(1-s)$.

Thus the equations (5.1a) and (5.1b) show that all the transforms conjugate to a given S_K have the same eigenvalues and the same corresponding carrier spaces.

A slight change of variable in Th. 72, p. 95 of Titchmarsh (1944) gives a convolution formula in the form

$$N \left[\int_0^\infty f(y)g(xy)dy \right] = G(s)F(1-s)$$

where $F(s) = N[f(x)]$ and $G(x) = N[g(x)]$.

$$N \left[\int_0^\infty (k_1(y)/y)(k_1(xy)/xy)dy \right] = \frac{K(s)K(1-s)}{s(1-s)}.$$

Thus for all S_K belonging to the same class, the integral $\int_0^\infty k_1(xy)k_1(y)/y^2 dy$ has the same value.

It is an easy corollary of this result to show that for the set of T_K for which $K(s)K(1-s)$ is a constant, the integral $\int_0^\infty k_2(xy)k_2(y)y^{-2}dy$ always has the same value.

There is only one transform conjugate to T_K , and that is seen to be AT_KA , which will have the same eigenvalues as T_K , but the carrier space of the eigenvalues will be the reflections in the origin of t of the original carrier set.

Now assume that a set E of t is given. Then the set of all S_K and T_K for which $K(s)K(1-s)$ is constant on E (the constant may differ for different K) form a subgroup G_E . Equations (5.1a)–(5.2b) show that G_E is a normal subgroup. Further, since $S_K S_L = T_K T_M$ and $S_K T_M = T_K S_L$ where $M(s) = L(1-s)$, the cosets $S_K G_E$ and $T_K G_E$ are both equal. Thus the quotient group G/G_E is commutative.

6

Of the unlimited number of subgroups of the group of transforms, we will only mention three which have interesting images in the $k(x)$ kernels.

The first such subgroup is that in which the $K(s)$ has a real period a . Stated more carefully, it is the subgroup for which $K(s) = K(\frac{1}{2} + it) = K(s + ia) = K(\frac{1}{2} + it + ia)$ for some given a .

For the S_K , we have

$$\begin{aligned} x^{ia} k_1(x) &= (2\pi)^{-1} \int_{-\infty}^{\infty} \frac{x^{\frac{1}{2}-it+ia} K(\frac{1}{2}+it)}{\frac{1}{2}-it} dt \\ &= (2\pi)^{-1} \int_{-\infty}^{\infty} \frac{x^{\frac{1}{2}-it} K(\frac{1}{2}+it)}{\frac{1}{2}-it-ia} dt. \end{aligned}$$

So

$$(6.1) \quad (x^{ia} - 1)k(x) = ia(2\pi)^{-1} \int_{-\infty}^{\infty} \frac{x^{\frac{1}{2}-it} K(\frac{1}{2}+it)}{(\frac{1}{2}-it)(\frac{1}{2}-it-ia)} dt.$$

Also

$$\begin{aligned} x^{ia-1} k_1(x) dx &= (2\pi)^{-1} \int_{-\infty}^{\infty} \frac{(x^{\frac{1}{2}+it+ia} - 1) K(\frac{1}{2}+it)}{(\frac{1}{2}-it+ia)(\frac{1}{2}-it)} dt \\ &= (2\pi)^{-1} \int_{-\infty}^{\infty} \frac{x^{\frac{1}{2}-it} K(\frac{1}{2}+it)}{(\frac{1}{2}-it)(\frac{1}{2}-it-ia)} dt \\ &\quad - (2\pi)^{-1} \int_{-\infty}^{\infty} \frac{K(\frac{1}{2}+it)}{(\frac{1}{2}-it-ia)(\frac{1}{2}-it)} dt, \end{aligned}$$

where by splitting into partial fractions or by using equation (6.1) the second term vanishes.

Thus we obtain

$$(6.2) \quad (x^{ia} - 1)k_1(x) = ia \int_1^x x^{ia-1} k_1(x) dx.$$

By differentiating equation (6.2), it is easy to see that $k_1'(x)=0$ almost everywhere. It is equally clear that in intervals $I_n=(e^{2n\pi/a}, e^{2(n+1)\pi/a})$, $k_1(x)$ is absolutely continuous. Thus, by Titchmarsh (1944, p. 365), $k_1(x)$ is constant on each of the intervals I_n . We may then verify that the solution of equation (6.2) is $k_1(x)=\sum_n C_n \chi_{I_n}$, where χ_{I_n} is the characteristic function of the interval I_n and the C_n are arbitrary constants. This is done by simple substitution in which it is noticed that the integral $\int x^{ia-1} k_1(x) dx$ vanishes when taken over any interval I_n .

Equation (1.8) can then be used to derive the corresponding result for the T_K ; this gives (6.3)

$$k_2(x)/x = \sum_n C_n \chi_{I_n}.$$

The commutator group is easily obtained.

$$\begin{aligned} T_K^{-1} T_L^{-1} T_K T_L [F(s)] &= F(s) \\ T_K^{-1} S_L^{-1} T_K S_L [F(s)] &= K(1-s)/K(s) \cdot F(s) \\ S_K^{-1} T_L^{-1} S_K T_L [F(s)] &= K(s)/K(1-s) \cdot F(s) \\ S_K^{-1} S_L^{-1} S_K S_L [F(s)] &= K(s)L(1-s)/K(1-s)L(s) \cdot F(s) \end{aligned}$$

All of the above transforms are of the type T_M where $M(s)M(1-s)=1$.

Conversely, every T_M with $M(s)M(1-s)=1$ can be expressed in the form of the third equation above by writing $K(s)=[M(s)]^{\frac{1}{2}}$.

The S_M transforms with $M(s)M(1-s)=1$ are usually called Watson transforms. The commutator subgroup is the set of transforms AS_M , where the S_M are Watson transforms.

The third subgroup of transforms is the set with $K(s)$ an entire function of the exponential type.

Dealing with the S_K transforms, we note that $(K(s)-K(1))/(1-s)$ is analytic and also of the exponential type.

The required result follows from a rewording of the Paley-Weiner theorem (Boas, 1954, p. 103). It reads as follows:

$H(s)$ is of the exponential type T and belongs to L^2 on the t -axis, if and only if

$$H(s) = \int_{e^{-T}}^{e^T} u^{s-1} h(u) du,$$

where $h(u)$ belongs to L^2 (e^{-T} , e^T).

In our particular case, writing $\varphi(x)=1$ for $t>1$ and $=0$, otherwise, we have

$$\begin{aligned} N^{-1} \left[\frac{K(s)-K(1)}{1-s} \right] &= x^{-1} (k_1(x) - K(1)\varphi(x)) \\ &= 0 \text{ for } x > e^T \text{ and for } x < e^{-T}. \end{aligned}$$

Thus

$$k_1(x) = \begin{cases} K(1) & \text{for } x > e^T \\ 0 & \text{for } x < e^{-T}. \end{cases}$$

The corresponding formula for the T_K is

$$k_2(x) = \begin{cases} K(1)x & \text{for } x < e^{-T} \\ 0 & \text{for } x > e^T. \end{cases}$$

References

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School of Mathematics

The University of New South Wales
Kensington

Annual Reports by the President and Council

PRESENTED AT THE ANNUAL MEETING OF THE SOCIETY, APRIL 5, 1961

The President's Report

At the outset, may I express my sincere appreciation of the honour conferred on me by the Council in nominating me as your President, particularly since it was made during my absence overseas on extended leave, the annual meeting and installation to office occurring only a few days after my return.

It has been a most successful year, and a great privilege to have worked with folk of the calibre of our executive officers, councillors, and office staff, and I thank them heartily for the kindness, encouragement and help which they, individually and collectively, have given me throughout my service as councillor, treasurer, Vice-President, and last year as President.

Mr. Harley Wood, Government Astronomer, and Past President of this Society, who had previously served as Honorary Administration Secretary, returned to that office in 1958 and remained therein for me as experienced adviser and friend. Dr. Alan Day, our Honorary Editorial Secretary in 1959, also remained to carry out his difficult job with enthusiasm and ability, not only making the usual arrangements regarding referees, costing, and the printing of papers in our Journal, but introducing innovations such as the publication of the Journal in bi-monthly parts, which is of advantage to authors and assists us financially, and the printing of special notices of our monthly meetings for distribution in those places where our proceedings are, or should be, of interest. These notices contributed, in no small measure, to the marked increase in attendance at our meetings. Mr. Adamson, serving his third term as Honorary Treasurer, has again demonstrated that our finances are in safe hands. The library committee, under the Chairmanship of Mr. Poggendorf, Honorary Librarian, held several meetings, and recommended disposal, to best advantage of ourselves and the recipients, of our holdings of various journals, periodicals and books no longer retained on our exchange list or suitable for retention in our library and the acquisition by exchange, or purchase, of those publications considered useful to the Society.

The Immediate Past President, Mr. Harper, acted for me at the April Council meeting and the May General meeting when an accident and subsequent sojourn in hospital prevented my attendance. Mr. McCarthy, a Past President, took the chair at the August Council meeting when I was unavoidably absent.

The other members of the Council have co-operated with the Executive in making the business of the Council proceed smoothly, expeditiously, and harmoniously, and their interest is evidenced in other ways such as the nomination of new members, Father Fynn's willingness to give an address on "Chilean Earthquakes" at a general meeting, and so on. We are especially pleased to see that the number of Associate Members, i.e. undergraduates and spouses of members, is steadily increasing, because therein lies future membership potential.

In July 1960, the Royal Society of London, senior scientific Society of the world, celebrated the Tercentenary of its foundation by a great gathering in that city of representatives of the world's principal centres of research and learning. Such an internationally significant occasion recalls that from its inception the chief concern of the Royal Society of London has been to maintain relations with men of science throughout the world. Even during major wars which England has waged, such as the Napoleonic wars and the American Revolution, here was one Society where nationality did not prevent men of science of every known discipline from friendly communication with each other. We are honoured in that several of our Honorary Members, and Members, are Fellows of that august body and know that some were present at the Tercentenary celebrations, but we were pleased to send the Royal Society of London our heartiest congratulations as one of its many daughter Royal Societies of similar aim in the British Commonwealth.

During the year the Royal Australian Chemical Institute asked to be supplied with a history of this Society for publication in their Journal. This was kindly prepared by Dr. W. R. Browne, a distinguished Past President of this Society. Council adopted my suggestion that an Addendum, containing the list of Past Executive Officers since our inception in 1821, be added, and that reprints of the whole, available by courtesy of the Royal Australian Chemical Institute, be obtained for members. This will be the first record of its kind compiled by the Society, and could perhaps be kept up to date decennially.

At our October meeting I had the great privilege of admitting two distinguished Australians as Honorary Members of this Society in the persons of Sir Lawrence Bragg, F.R.S., Nobel Prize winner and President of the Royal Institution, London, and Sir Charles Bickerton Blackburn, Chancellor of the University of Sydney, also of world reputation and for whom we hold sincere affection. Sir Lawrence Bragg's address, later than evening, was a model in substance, interest and delivery, which would be difficult to match. We are proud of the quality of our Honorary Members, most of whom reside abroad, as does Sir Lawrence, and have been unable to receive personal welcome.

It can be seen that our Society has never lost interest in the specialist societies and institutions which necessarily have had to form independent bodies in their own disciplines. It remains a society of amateurs of science and, as such, academical qualifications are not essential for membership, but there is required, as in 1821, a desire to learn and to give of one's knowledge. It is not surprising therefore to find members of specialist bodies, which do require academic qualification, among our most enthusiastic members. Here we can learn something of what is being done in other disciplines and, on the broader knowledge, not only have a better understanding of our own calling but, by lifting our eyes above the rut of our (necessarily in these days) restricted specialized work, be able to see what goes on in the world around us.

In company with Mr. Harley Wood I called on our Patron, the State Governor, Sir Eric Woodward, on 28th July, when he stressed the important part that Science and Scientific bodies are playing in the world today. I also paid a courtesy call to the then Chairman of the Public Service Board, the late Wallace Wurth, and attended on the Society's behalf the following functions:

Annual Meeting of the Royal Australian Chemical Institute and address by Sir Alexander Todd, 1.9.60.

The Opening of the New Metallurgical Laboratory of the University of New South Wales, 6.9.60.

The Opening of the new wing to the Australian Museum, 11.8.60.

The Opening of the new Chemistry School at the University of Sydney, 28.6.60.

The Opening of the Engineering and Metallurgy Building at the Australian Atomic Energy Commission Research Establishment at Lucas Heights, 18.11.60.

The Annual Conservation Conference, N.S.W., 13.8.60.

The Annual Exhibition of the Institute of Physics, 16.8.60.

The annual functions of the Sydney division of the Institute of Engineers, 12.10.60, the Chamber of Manufacturers of N.S.W., 15.9.60, and the Institute of Surveyors, 29.3.61.

The Sir William Macleay Memorial Lecture, under the auspices of the Linnean Society, N.S.W., by Professor Th. Dobzhansky, on 29.6.60.

The George Judah Cohen Memorial Lecture by Professor Briggs, 1.11.60.

The World Refugee Year Committee, final meeting, 16.9.60.

State Reception to delegates International Symposium on Chemistry of Natural Products, 22.8.60.

The Meeting of the Board of Visitors, Sydney Observatory, 20.4.60.

Annual Presentation of Medals and Diplomas, Sydney Technical College, 15.6.60.

Annual Meeting, Sydney Branch, Australasian Institute of Mining and Metallurgy, 16.9.60.

Chaired the Meeting at the School of Chemistry, Sydney University, 13.10.60, when the Liversidge Lecture was delivered by our President-Elect, Professor Le Fèvre, F.R.S.

Having taken my immediate presidential predecessor's words to heart, I talked personally with our Armidale members, conducted preliminary correspondence and visited Armidale on December 12, 1960, when I was pleased to address a well attended meeting at the University of New England regarding the establishment of a branch of the Society in that centre. At the meeting it was decided to form a branch, to be called the New England Branch, and Professor P. D. F. Murray and Dr. R. L. Stanton were elected respectively provisional Chairman and Secretary-Treasurer. The inaugural meeting of the Branch was held on March 24, 1961. It was a most successful function to which I was accompanied by Past Presidents Drs. Ida and W. R. Browne, and other members. Further details are recorded in the Report of Council.

It was my sorrow to represent the Society at a number of sad occasions. During the year the Society suffered the loss of a number of its distinguished members. Their records will be found in the Obituary, but I feel impelled here to make special mention of

certain of those for whom our sense of loss is most keenly felt. Our Patron, Lord Dunrossil, Governor-General, after a lifetime of service to his country and his fellow men, died in office. He was a gentleman who in his all too short sojourn amongst us had endeared himself to all Australians. Professors Charles Fawsitt and Henry Priestley, both eminent scientists, Past Presidents, and well beloved members, and Sir Hugh Poate, distinguished surgeon, were all members of over 40 years' standing. We also sympathize sincerely with those scientific bodies of which Dr. A. B. Edwards was a member, and to which he so freely contributed his knowledge, in their loss. Only last year this Society had awarded him the Clarke Medal for distinguished contributions in the field of geology.

Finally, I tender on behalf of the Society our heartfelt thanks to all who have contributed to our welfare during the past year, to the Government of N.S.W. for its continued support, and particularly to our lecturers, members of sub-committees of Council, and our full-time Assistant Secretary, Miss Ogle, and Mrs. Huntley our Assistant Librarian, for their ready assistance.

H. A. J. DONEGAN,
President.

Report of the Council for the Year Ended 31st March, 1961

At the end of the period under review the composition of the *membership* was 321 ordinary members, 8 associate members and 10 honorary members; 25 new members were elected and 12 members resigned. Two names were removed from the list of members under Rule XVIII. It is with regret that we announce the loss by death of The Rt. Hon. Viscount Dunrossil, Charles Edward Fawsitt, Neil Ernest Goldsworthy, Herbert Richard Harrington, Daryl Robert O'Dea, Sir Hugh Poate and Henry Priestley.

Nine monthly *meetings* were held. The Proceedings of the meetings have been published in the notice paper and appear elsewhere in this issue of the "Journal and Proceedings". The members of Council wish to express their sincere thanks and appreciation to the seven speakers who contributed to the addresses, and also to the members who read papers at the September and December monthly meetings.

At the meeting on 3rd August a film on Chile and the Andes Mountains, taken by the President during a trip, was shown.

The meeting on 5th October was held conjointly with the Institute of Physics, the Chemical Society of the University of Sydney and the Chemical Society of the University of New South Wales and was devoted to a lecture by Sir Lawrence Bragg, F.R.S., entitled "The Royal Institution".

The *Annual Social Function* was held on 21st March and was attended by 55 members and guests. Mr. M. Tachibana, of the Japanese Consulate, was guest speaker.

The *Clarke Medal* for 1961 was awarded to Mr. C. A. Gardner, former Government Botanist of Western Australia, for distinguished contributions in the field of botany.

The *Society's Medal*, for scientific contributions and for services to the Society, was awarded to Professor T. Griffith Taylor, F.A.A.

No award was made for the *James Cook Medal*.

The *Edgeworth David Medal* for 1960 was awarded to Professor R. D. Brown, Chemistry Department,

Monash University, Melbourne, for outstanding contributions in the field of chemistry.

The *Archibald D. Olle Prize* was awarded to Mr. H. G. Golding for his paper entitled "Variation in Physical Constitution of Quarried Sandstones from Sydney and Gosford" published in Volume 93 of the Society's "Journal and Proceedings".

The *Liversidge Research Lecture for 1960*, entitled "Applications in Chemistry of Properties Involving Molecular Polarizability", was delivered by Professor R. J. W. Le Fèvre, F.R.S., F.A.A., School of Chemistry, University of Sydney (see *Journal and Proceedings*, v, 95, pp. 1-11).

During the year it was found necessary to have made a new die for the Society's Medal, as the one made in 1884 could not be located. The total cost of the die and 25 medals was £276.

At the June meeting of the Council it was decided, commencing with Volume 94, to publish the "Journal and Proceedings" in six parts. Parts 3 and 4 of Volume 93 and the first five parts of Volume 94 were published. To deal with one paper whose rapid publication was thought to be in the national interest a part was published early. The publication of the Clarke Memorial Lecture by Dr. D. E. Thomas was assisted by a grant of £150 through the Commonwealth Scientific Publications Committee.

The Royal Australian Chemical Institute requested a *History of the Royal Society of New South Wales* for publication in the Institute's *Proceedings*, and Dr. W. R. Browne must be thanked for preparing a history. An addendum giving the list of executive officers of our Society since 1821 has been added to this and it is intended to make it available to members as a reprint.

The Society has again received a *grant from the Government* of New South Wales, the amount being £750. The Government's interest in the work of the Society is much appreciated.

The Society's *financial statement* shows a deficit of £138 11s. 7d.

The *Section of Geology* held five meetings during the year.

Council held eleven ordinary meetings. The attendance of members of Council was as follows: Mr. H. A. J. Donegan 9, Mr. J. L. Griffith 8, Mr. F. N. Hanlon 5, Mr. A. F. A. Harper (absent on leave for 7 meetings) 4, Mr. F. D. McCarthy 8, Mr. Harley Wood 11, Dr. A. A. Day 7, Mr. C. L. Adamson 7, Father A. G. Fynn 9, Mr. J. W. Humphries (absent on leave for one meeting) 9, Mr. A. H. Low 9, Mr. H. H. G. McKern 9, Mr. W. H. G. Poggendorff 4, Mrs. K. M. Sherrard 10, Mr. G. H. Slade (absent on leave for 2 meetings) 3, Mr. W. B. Smith-White 6, Mr. N. W. West 8, Mr. H. F. Whitworth 5.

The Society's representatives on *Science House Management Committee* were Mr. H. A. J. Donegan and Mr. C. L. Adamson.

Dr. Day, on behalf of the President, attended the Commemoration of the Landing of Captain Cook at Kurnell.

The President attended the meetings of the Board of Visitors of the Sydney Observatory.

On 28th July the President and the Honorary Treasurer waited on His Excellency the Governor of New South Wales.

The President and Mr. J. L. Griffith were present at the Official Opening of the Engineering and Metallurgy Building at the Australian Atomic Energy Commission

Research Establishment which was opened by the Prime Minister.

The President visited Armidale on 13th December to attend a meeting in connection with the *formation of a branch of the Society*. There were about 30 at the meeting, which decided to form a New England Branch of the Royal Society of New South Wales and elected Dr. P. D. F. Murray, F.A.A., as provisional chairman. The first meeting of the branch was held on 24th March and Professor K. E. Bullen, F.R.S., F.A.A., delivered the Inaugural Address. This meeting, which was a well attended one, included the presence of the President and Past Presidents Drs. Ida A. and W. R. Browne.

Soil Science Committee—The Committee had prepared its report on "Post Cretaceous Chronology" and this had been forwarded to the Australian Academy of Science.

The Library—Periodicals were received by exchange from 392 societies and institutions. In addition the amount of £90 was expended on the purchase of 11 periodicals.

Among the institutions which made use of the library through the inter-library loan scheme were:

N.S.W. Govt. Depts.—Department of Agriculture, Botanic Gardens, Forestry Commission, Main Roads Board, Department of Health, Sydney County Council, W.C. & I. Commission, Division of Wood Technology.

Commonwealth Govt. Depts.—C.S.I.R.O. Head Office, Melbourne; Library, Canberra; Chemical Research Laboratories, Melbourne; Coal Research Section, Sydney; Division of Fisheries, Cronulla; Division of Food Preservation, Homebush; National Standards Laboratory, Sydney; Regional Pastoral Laboratory, Deniliquin; The Ian Clunies Ross Animal Research Laboratory, Parramatta; Division of Textile Physics, Ryde; Division of Tribophysics, Melbourne; Division of Tropical Pastures, Brisbane; Division of Wool Research, Ryde; Australian Atomic Energy Commission; Bureau of Mineral Resources; Commonwealth Bureau of Statistics; Department of Supply, Aeronautical Research, Melbourne; Research Department, Reserve Bank of Australia, Sydney.

University and Colleges—Sydney Technical College; Wollongong Technical College; Newcastle University College; Australian National University; Mount Stromlo Observatory; University of Sydney; University of New South Wales; University of New England; University of Melbourne; University of Queensland; University of Tasmania; Victoria University of Wellington, New Zealand.

Companies—Australian Iron & Steel Ltd.; J. Bayley & Sons; Lewis Bergers; B.H.P. Co. Ltd.; C.S.R. Co. Ltd.; Wm. Cooper & Bros.; Electrolytic Zinc Co.; John Lysaght Pty. Ltd.; Monsanto Chemicals; Mount Isa Mines Ltd.; Standard Telephones & Cables; Unilever; Union Carbide Aust. Ltd.; Wheat Industries Aust. Pty. Ltd.; Philips Electrical Industries Pty. Ltd.

Research Institutes—Australian Institute of Anatomy, Canberra; Institute of Dental Research; Drug Houses of Australia; Medical Research Institute, Royal North Shore Hospital; N.S.W. Cancer Council.

Museums and Public Libraries—The Australian Museum; National Museum of Victoria; Library Board of Western Australia; Bankstown Municipal Library; Library Board of New South Wales.

HARLEY WOOD,
Honorary Secretary.

Financial Statement

BALANCE SHEET AS AT 28th FEBRUARY, 1961

LIABILITIES		£	s.	d.	£	s.	d.
1960							
200	Accrued Expenses						
36	Subscriptions Paid in Advance				42	0	0
177	Life Members' Subscriptions—Amount carried forward				167	2	0
	Trust and Monograph Capital Funds (detailed below)—						
	Clarke Memorial	1,908	10	4			
	Walter Burfitt Prize	1,129	3	7			
	Liversidge Bequest	707	7	4			
	Monograph Capital Fund	4,421	8	2			
	Ollé Bequest	157	1	7			
8,163					8,323	11	0
23,423	Accumulated Funds				23,211	2	7
—	Employees' Long Service Leave Fund Provision ..				100	0	0
£31,999					£31,843	15	7

ASSETS		£	s.	d.	£	s.	d.
1,224	Cash at Bank and in Hand				998	3	8
	Investments—						
	Commonwealth Bonds and Inscribed Stock—						
	At Face Value—held for:						
	Clarke Memorial Fund	1,800	0	0			
	Walter Burfitt Prize Fund	1,000	0	0			
	Liversidge Bequest	700	0	0			
	Monograph Capital Fund	3,000	0	0			
	General Purposes	1,960	0	0			
8,460					8,460	0	0
—	Fixed Deposit Long Service Leave Fund ..				100	0	0
	Debtors for Subscriptions	41	0	4			
	Less Reserve for Bad Debts	41	0	4			
14,835	Science House—One-third Capital Cost				14,835	4	4
6,800	Library—At Valuation				6,800	0	0
	Furniture and Office Equipment—At Cost, less						
663	Depreciation				633	17	7
16	Pictures—At Cost, less Depreciation				15	10	0
1	Lantern—At Cost, less Depreciation				1	0	0
£31,999					£31,843	15	7

TRUST AND MONOGRAPH CAPITAL FUNDS

	Clarke Memorial			Walter Burfitt Prize			Liversidge Bequest			Monograph Capital Fund			Ollé Bequest		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Capital at 28th February, 1961	1,800	0	0	1,000	0	0	700	0	0	3,000	0	0	—		
Revenue—															
Balance at 29th February, 1960	42	0	2	167	8	9	6	8	3	1,302	1	0	144	16	1
Income for twelve months	66	16	10	37	1	6	25	19	1	119	7	2	42	5	6
	108	17	0	204	10	3	32	7	4	1,421	8	2	187	1	7
Less Expenditure ..	0	6	8	75	6	8	25	0	0	—			30	0	0
Balance at 28th February, 1961	£108	10	4	£129	3	7	£7	7	4	£1,421	8	2	£157	1	7

ACCUMULATED FUNDS

	£	s.	d.	£	s.	d.
Balance at 29th February, 1960	23,423	10	6			
Add Decrease in Reserve for Bad Debts ..	46	2	8			
	23,469	13	2			
Less—						
Transfer to Long Service Leave Fund						
Provision	100	0	0			
Bad Debts Written Off	19	19	0			
Deficit for twelve months	138	11	7			
	258	10	7			
Balance at 28th February, 1961	£23,211	2	7			

Auditors' Report

The above Balance Sheet has been prepared from the Books of Account, Accounts and Vouchers of the Royal Society of New South Wales, and is a correct statement of the position of the Society's affairs on 28th February, 1961, as disclosed thereby. We have satisfied ourselves that the Society's Commonwealth Bonds and Inscribed Stock are properly held and registered.

HORLEY & HORLEY,
Chartered Accountants,

Prudential Building,
39 Martin Place, Sydney,
27th March, 1961.

Registered under the Public Accountants
Registration Act 1945, as amended.

(Sgd.) C. L. ADAMSON,
Honorary Treasurer.

INCOME AND EXPENDITURE ACCOUNT

1st March, 1960, to 28th February, 1961

		£	s.	d.
1960				
2	Advertising	—		
6	Annual Social Function	—		
31	Audit	31	10	0
—	Branches of the Society	13	14	0
104	Cleaning	109	0	0
36	Depreciation	34	3	3
50	Electricity	49	5	0
1	Entertainment	5	7	6
41	Insurance	39	9	2
108	Library Purchases	90	10	3
361	Miscellaneous	204	2	4
137	Postages and Telegrams	213	11	3
	Printing Journal—			
	Vol. 93, Parts 3-4	£334	16	0
	Binding	35	0	0
	Vol. 94, Parts 1-4	1,300	15	6
1,531			1,670	11 6
93	Printing—General		167	9 3
26	Rent—Science House Management		1,083	16 6
6	Repairs		4	8 10
1,218	Salaries		1,310	2 1
47	Telephone		38	0 6
£3,798			£5,065	1 5

		£	s.	d.
1960				
809	Membership Subscriptions	843	13	6
9	Proportion of Life Members' Subscriptions	9	9	0
220	Subscriptions to Journal	271	10	1
750	Government Subsidy	750	0	0
1,165	Science House Management—Share of Surplus	2,196	10	2
—	Annual Social Function	6	14	8
81	Interest on General Investments	87	2	4
	Reprints—			
	Receipts	£474	19	10
	Expenditure	359	1	8
37			115	18 2
440	Sale of Back Numbers of the Journal	296	17	9
146	Sale of Periodicals <i>ex</i> the Library	198	14	2
30	Publication Grant	150	0	0
111	Deficit for twelve months	138	11	7
£3,798			£5,065	1 5

Obituary

Professor Charles Edward Fawsitt, Emeritus Professor of Chemistry in the University of Sydney and a former President of the Society, died on 16th November, 1960. He was born in Glasgow in 1878, was educated at the Glasgow High School and the University of Edinburgh, and did post-graduate work in the Technische Hochschule, Aachen, and the Universities of London, Birmingham and Leipzig. From 1904 to 1908 he was a lecturer in Metallurgical Chemistry in the University of Glasgow. In 1909 he was appointed to the Chair of Chemistry in the University of Sydney—an appointment he held with distinction until his retirement in 1946. His research interests lay mainly in the field of metallic corrosion and chemical kinetics.

Professor Fawsitt took a keen interest in educational matters, and had a friendly liaison with the Education Department and secondary schools of New South Wales. A loyal Scot and a quietly religious man, he was also a musician, giving much pleasure in his playing of the piano.

The Royal Society of New South Wales was privileged to have Professor Fawsitt as a member for fifty-one years. He was an enthusiastic supporter of the Society, contributed seven papers to the *Journal and Proceedings*, and, in 1919, served the Society as President. He was one of the original members of the Royal Australian Chemical Institute, and was its Federal President in 1924. For long he will be remembered for his old-world courtesy, considerateness, friendliness and helpfulness to all.

Dr. Neil Ernest Goldsworthy died after a short illness on 26th September, 1960, at the age of sixty-three. He was elected to membership of the Society in 1947. At the time of his death he was Director of the Institute of Dental Research, United Dental Hospital, Sydney, a post which he had occupied with distinction from 1946. Dr. Goldsworthy was educated at Newcastle High School and the University of Sydney, and proceeded to the London School of Hygiene and Tropical Medicine and then to Cambridge University for post-graduate work. He held the following degrees and distinctions: M.B., Ch.M. (Sydney, 1921), D.T.M. & H., D.P.H. (Cambridge, 1926), Ph.D. (Cambridge, 1928), M.C.P.A. (1956).

After a short period as a consultant pathologist, Dr. Goldsworthy joined the staff of Sydney University as lecturer in bacteriology in 1931. In addition he was an Honorary Assistant and later Honorary Consultant at the Royal North Shore Hospital, Sydney. Among many other services to the community he was a member of the Medical Research Advisory Committee and of the Dental Research Advisory Committee; he was also a co-opted member of the Nutrition Committee of the National Health and Medical Research Council. He published many scientific papers and always found time to encourage those who showed an interest in research. In honour of his twenty years' service as Honorary Secretary of the Society for Experimental Biology of N.S.W., that society inaugurated in 1955 the triennial Goldsworthy lectures. Neil Goldsworthy will be remembered for his wide range of knowledge,

meticulous attention to detail, integrity and tenacity in research.

Herbert Richard Harrington, a member of the Society since 1934, died on 20th April, 1960.

Mr. Harrington was employed throughout the greater part of his career as a teacher of Electrical Engineering in the Sydney Technical College, and later, as a lecturer in the University of Technology (now the University of New South Wales). His speciality was electrical laboratory measurements. He had, too, a remarkable knowledge of botanical and biological subjects, so much so that he could give an extempore address in these fields and hold one's interest for an hour without trouble.

His deepest interest was in the field of optics, particularly in the microscope and the camera, both of which he applied most effectively in the botanical and biological work. He originated a new system of colour photography, the further development of which was interrupted by war-time conditions. His recognition as an authority on optical matters led to his requisition by the Army Authorities to assist in the development of a special high-speed camera to investigate field-gun recoil, movement and mechanism. Similarly he was able to assist the New South Wales Police Department in setting up microscopic and other scientific equipment in that Department's Scientific Bureau. He also acted in an advisory capacity on photomicrography to the Department of Dentistry in the University of Sydney.

Daryl Robert O'Dea died on 19th February, 1961. He was elected to membership in 1951.

Sir Hugh Raymond Guy Poate was elected to Membership of the Society in 1919 and in recent years was a Life Member. He died on 27th January, 1961.

Throughout his career, Hugh Poate devoted himself to the service of his country and of surgery with great enthusiasm and boundless energy. He was educated at Sydney Grammar School and Sydney University and in 1907, upon graduation, became resident medical officer at the Royal Prince Alfred Hospital. He visited England the following year and in 1909 gained a Fellowship of the Royal College of Surgeons. (He was the first graduate of the University of Sydney to do this.)

Poate was early recognized as a brilliant surgeon whose speed and dexterity were combined with a thorough knowledge of anatomy. His operative work covered an extraordinary range, including orthopaedic, cranial, thyroid and abdominal surgery. For his work on diseases of the thyroid gland, especially in the treatment of hyperthyroidism, he was widely honoured and is now best known.

During the Great War he was in Europe, including Gallipoli, on active service with the Australian Army Medical Corps. Although invalided home in 1917, he continued active work for the A.A.M.C. in Sydney hospitals. From 1929 to 1947 he was a consulting surgeon to the Royal Australian Air Force.

Poate was a Foundation Fellow of the Royal Australasian College of Surgeons and in 1945 was elected president of the College. He joined the Order of St. John of Jerusalem in 1913 and gave much service to the Order. In 1955 he received from Her Majesty the Queen the Bailiff Grand Cross of the Order, a very high and rare honour. In 1947 he was created a Member of the Royal Victorian Order, and in 1952 was created Knight Bachelor.

Sir Hugh Poate's attractive personality, warm friendliness and integrity drew to him a wide circle of friends and admirers, even though at times he forthrightly, and on occasion bluntly, expressed his judgment of what was just and right. By his passing the Society has lost a member admired as a man, respected by his juniors as an adviser and above all honoured as a surgeon.

Professor Henry Priestley, Emeritus Professor of Biochemistry in the University of Sydney, died at the age of 77 on 28th February, 1961. He was born in England but came to Australia with his parents at the age of two. After a brilliant undergraduate career at Sydney University he spent three years at the Lister Institute of Preventive Medicine, London, and then was appointed lecturer in physiology in his alma mater. From 1921 to 1938 he was Associate Professor and head of the Department of Biochemistry in the Uni-

versity, and in 1938 was appointed Professor. From 1945 to 1948, when he retired, he was Dean of the Faculty of Science. He was responsible for an important innovation in the Science courses at Sydney University in the introduction of compulsory work in the History and Philosophy of Science. He continued to act as an examiner in this subject after his retirement. He was known throughout the University by the affectionate title "Uncle Henry", and his friendliness and generosity towards both students and staff were widely appreciated.

Professor Priestley was elected to membership of the Society in 1918 and served as President in 1942. He contributed one paper to the Journal and Proceedings.

During the Second World War Professor Priestley was called upon by the Commonwealth Government to act as nutrition adviser; in the course of this work, additional to his normal academic duties, he was able to give public expression to several important observations on dietary deficiencies of Australian meals in both peace and war. After his retirement Priestley gained some renown as an amateur weaver, ultimately becoming president of the Spinners and Weavers' Guild of N.S.W. In this period also he continued to serve his University as a member of its Senate. By his death the community has lost a generous and well-loved man whose work in many fields contributed substantially to the common welfare.

Abstract of Proceedings, 1960

6th April, 1960

The ninety-third Annual and seven hundred and fifty-fifth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. A. F. A. Harper, was in the chair. Forty-two members and visitors were present.

Desmond Leslie Strusz and Howard Gordon Wilshire were elected members of the Society.

The following awards of the Society were announced :
The James Cook Medal for 1959 : Dr. Albert Schweitzer.

The Society's Medal for 1959 : Dr. Ida A. Browne.

The Clarke Medal for 1960 : Dr. A. B. Edwards.

The Walter Burfitt Prize for 1959 : Professor F. J. Fenner.

The Archibald D. Olle Prize : Professor G. Bosson.

The Annual Report of the Council and the Financial Statement were presented and adopted.

Messrs. Horley and Horley were re-elected as Auditors to the Society for 1960-61.

The following papers were read by title only :
"The Measurement of Time in Special Relativity", by S. J. Prokhovnik ; "The Geology of the Parish of Mumbil, near Wellington, N.S.W.", by D. L. Strusz ; "Minor Planets Observed at Sydney Observatory during 1959", by W. H. Robertson.

Office-bearers for 1960-61 were elected as follows :

President : H. A. J. Donegan, M.Sc.

Vice-Presidents : J. L. Griffith, B.A., M.Sc. ; F. N. Hanlon, B.Sc. ; A. F. A. Harper, M.Sc. ; F. D. McCarthy, Dip.Anthr.

Hon. Secretaries : Harley Wood, M.Sc. ; A. A. Day, B.Sc. (Syd.), Ph.D. (Cantab.).

Hon. Treasurer : C. L. Adamson, B.Sc.

Members of Council : A. G. Fynn, B.Sc. ; J. W. Humphries, B.Sc. ; A. H. Low, M.Sc. ; H. H. G. McKern, M.Sc. ; W. H. G. Pogendorff, B.Sc. (Agr.) ; Kathleen M. Sherrard, M.Sc. (Melb.) ; G. H. Slade, B.Sc. ; W. B. Smith-White, M.A. ; Mr. N. W. West, B.Sc. ; H. F. Whitworth, M.Sc.

The retiring President, Mr. A. F. A. Harper, delivered his Presidential Address entitled "Research Development and the Maintenance of Standards in Heat at the National Standards Laboratory, Sydney".

At the conclusion of the meeting the retiring President welcomed Mr. H. A. J. Donegan to the Presidential Chair.

4th May, 1960

The seven hundred and fifty-sixth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

Mr. A. F. A. Harper, Vice-President, was in the chair. Thirty-three members and visitors were present.

Bruce William Chappell, Jack Middlehurst, Victoria Ross and Vivian Endel Thomson were elected members of the Society.

Sir Lawrence Bragg, F.R.S., and Sir Charles Bickerton Blackburn were elected to Honorary Membership of the Society.

The following papers were read by title only :
"Kinetics of Chain Reactions", by R. C. L. Bosworth and C. M. Groden ; "An Occurrence of Buried Soils at Prospect, N.S.W.", by C. A. Hawkins and P. H. Walker.

An address entitled "The Phytotron and its Work" was delivered by Dr. L. T. Evans, of the C.S.I.R.O., Division of Plant Industry, Canberra.

1st June, 1960

The seven hundred and fifty-seventh General Monthly Meeting was held in the Hall of Science House Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. A. J. Donegan, was in the chair. Thirty-nine members and visitors were present.

Maurice James Puttock and Russell George Wylie were elected members of the Society.

An address on Blood was delivered by Mr. E. C. Mason, of the Blood Fraction Development Group of the Commonwealth Serum Laboratories, Melbourne.

6th July, 1960

The seven hundred and fifty-eighth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. A. J. Donegan, was in the chair. There were present thirty members and visitors.

The following papers were read by title only : "Net Electric Charges on Stars, Galaxies and 'Neutral' Elementary Particles", by V. A. Bailey ; "An Interpretation of the Lorentz Transformation Coordinates", by S. J. Prokhovnik ; "Electrode Shape and Finish in Applied Spectroscopy", by S. C. Baker ; "Resonance Absorption in a Cylindrical Fuel Rod with Radial Temperature Variation", by A. Reichel and A. Keane ; "Appraisal of Absolute Gravity Values for Gravity Base Station in Sydney, Melbourne and Adelaide", by I. A. Mumme ; "Stratigraphy of the Tamworth Group (Lower and Middle Devonian), Tamworth-Nundle District, N.S.W.", by K. A. W. Crook ; "Post-Carboniferous Stratigraphy of the Tamworth-Nundle District, N.S.W.", by K. A. W. Crook ; "Stratigraphy of the Parry Group (Upper Devonian-Lower Carboniferous), Tamworth-Nundle District, N.S.W.", by K. A. W. Crook.

Mr. Allen A. Strom, Chief Guardian of Fauna, Fauna Protection Panel, Chief Secretary's Department, gave an address on "The Work of the Fauna Protection Panel".

3rd August, 1960

The seven hundred and fifty-ninth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. A. J. Donegan, was in the chair. There were present ninety-seven members and visitors.

Hugh Francis Conaghan, William Ronald Grant Kemp, Burnett Mander-Jones and R. G. Wenham were elected members of the Society.

The following paper was read by title only: "The Palaeomagnetism of Some Igneous Rock Bodies in New South Wales", by R. Boesen, E. Irving and W. A. Robertson (communicated by Dr. W. R. Browne).

Film: "Chile and the Andes Mountains", taken by Mr. Donegan during a recent trip.

Address: "Chilean Earthquakes" was delivered by Father A. G. Fynn.

7th September, 1960

The seven hundred and sixtieth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. A. J. Donegan, was in the chair. There were present fifty-two members and visitors.

Erwin R. Tichauer was elected a member of the Society.

The following paper was presented: "Net Electric Charges on Stars, Galaxies and 'Neutral' Elementary Particles", by V. A. Bailey.

5th October, 1960

The seven hundred and sixty-first General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. A. J. Donegan, was in the chair. There were present ninety-three members and visitors.

The death was announced of Neil Ernest Goldsworthy on 26th September, 1960, a member since 1947.

Honorary membership was conferred on Sir Lawrence Bragg, F.R.S., and Sir Charles Bickerton Blackburn.

The following were elected members of the Society: George Earl Adkins, George Divnich, Allan Richard Horne, Rupert Thomas Leslie, Harry Albert Theodore Scholer.

The meeting took the form of a joint meeting with the Institute of Physics, the Chemical Society of the University of Sydney and the Chemical Society of the University of New South Wales. A lecture entitled "The Royal Institution" was delivered by Sir Lawrence Bragg, F.R.S.

2nd November, 1960

The seven hundred and sixty-second General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. A. J. Donegan, was in the chair. There were present sixty-seven members and visitors.

The following were elected members of the Society: Alfred Denys Mervyn Bell and Malcolm Charles Galloway.

The following addresses were given: "The Contribution of the Radiocarbon Method to Dating the Past", by Associate Professor J. H. Green, of the School of Nuclear and Radiation Chemistry, The University of New South Wales; "Carbon 14 Dating in Australian and Pacific Prehistory", by Mr. F. D. McCarthy, Curator of Anthropology, The Australian Museum.

7th December, 1960

The seven hundred and sixty-third General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. A. J. Donegan, was in the chair. There were present twenty-three members and visitors.

Raymond Augustine Burg, James Campbell Giffen, Charles Verling Gayer Phipps, Roger Albert Alfred Smith and Coleridge Anthony Wilkins were elected members of the Society.

The following papers were presented: "Kinetics of Chain Reactions", by R. C. L. Bosworth and C. M. Groden; "Resonance Absorption in a Cylindrical Fuel Rod with a Radial Temperature Variation", by A. Reichel and A. Keane; "An Interpretation of the Lorentz Coordinates", by S. J. Prokhovnik.

Members of the Society, April, 1961

The year of election to membership and the number of papers contributed to the Society's Journal are shown in brackets, thus : (1934 ; P8). * indicates Life Membership.

Honorary Members

- BLACKBURN**, Sir Charles Bickerton, K.C.M.G., O.B.E., B.A., M.D., Ch.M., Chancellor, University of Sydney. (1960)
- BRAGG**, Sir Lawrence, O.B.E., F.R.S., The Royal Institution, London. (1960)
- BURNET**, Sir Frank Macfarlane, O.M., Kt., D.Sc., F.R.S., F.A.A., Director, Walter and Eliza Hall Research Institute, Melbourne. (1949)
- FAIRLEY**, Sir Neil Hamilton, C.B.E., M.D., D.Sc., F.R.S., 73 Harley Street, London, W.1. (1951)
- FIRTH**, Raymond William, M.A., Ph.D., Professor of Anthropology, University of London, London School of Economics, Houghton Street, Aldwych, W.C.2, England. (1952)
- FLOREY**, Sir Howard, M.B., B.S., B.Sc., M.A., Ph.D., F.R.S., Professor of Pathology, Oxford University, England. (1949).
- O'CONNELL**, Rev. Daniel J., S.J., D.Sc., Ph.D., F.R.A.S., Director, The Vatican Observatory, Rome, Italy. (1953)
- OLIPHANT**, Sir Marcus L., K.B.E., Ph.D., B.Sc., F.R.S., F.A.A., Professor of Physics, Australian National University, Canberra, A.C.T. (1948)
- ROBINSON**, Sir Robert, M.A., D.Sc., F.R.S., F.C.S., F.I.C., Professor of Chemistry, Oxford University, England. (1948)

Members

- ADAMSON**, Colin Lachlan, B.Sc., 9 Dewrang Avenue, Avenue, North Narrabeen. (1944)
- ADKINS**, George Earl, A.S.T.C., C/o School of Mining Engineering and Applied Geology, University of N.S.W. (1960)
- ***ALBERT**, Adrien, D.Sc., Professor of Medical Chemistry, Australian National University, Canberra, A.C.T. (1938 ; P2)
- ***ALBERT**, Michael Francois, "Boomerang", Billyard Avenue, Elizabeth Bay. (1935)
- ALEXANDER**, Albert Ernest, Ph.D., Professor of Chemistry, University of Sydney. (1950)
- ***ALLDIS**, Victor le Roy, Box 37, Orange, N.S.W. (1941)
- ANDERSON**, Geoffrey William, B.Sc., c/o Box 30, P.O. Chatswood. (1948)
- ANDREWS**, Paul Burke, B.Sc., 5 Conway Avenue, Rose Bay. (1948 ; P2)
- ASTON**, Ronald Leslie, Ph.D., Associate Professor of Geodesy and Surveying, University of Sydney. (1930 ; **President 1948**)
- ***AUROUSSEAU**, Marcel, M.C., B.Sc., 229 Woodland Street, Balgowlah. (1919 ; P2)
- ***BAILEY**, Victor Albert, D.Phil., F.A.A., 80 Cremorne Road, Cremorne. (1924 ; P3)
- BAKER**, Stanley Charles, Ph.D., Department of Physics, Newcastle University College. (1934 ; P3)
- BANKS**, Maxwell Robert, B.Sc., Department of Geology, University of Tasmania, Hobart, Tas. (1951)
- ***BARDSLEY**, John Ralph, 29 Walton Crescent, Abbotsford. (1919)
- BASDEN**, Keith Spencer, B.Sc., School of Mining Engineering and Applied Geology, University of New South Wales, Kensington. (1951)
- BAXTER**, John Philip, C.M.G., O.B.E., Ph.D., F.A.A. Vice-Chancellor and Professor of Chemical Engineering, University of New South Wales, Kensington. (1950)
- BECK**, Julia Mary (Mrs.), B.Sc., Department of Geophysics, University of Western Ontario, London, Ont., Canada. (1950).
- BELL**, Alfred Denys Mervyn, B.Sc. (Hons.), School of Mining Engineering and Applied Geology, University of New South Wales, Kensington. (1960)
- ***BENTIVOGLIO**, Sydney Ernest, B.Sc.Agr., 42 Telegraph Road, Pymble. (1926)
- ***BISHOP**, Eldred George, 26A Wolsley Road, Mosman. (1920)
- BLANKS**, Fred Roy, B.Sc., 583 Malabar Road, Maroubra. (1948)
- BLASCHKE**, Ernest Herbert, 6 Illistron Flats, 63 Carabella Street, Kirribilli. (1946)
- BOLLIGER**, Adolph, D.Sc., Gordon Craig Urological Research Laboratory, Department of Surgery, University of Sydney. (1933 ; P30 ; **President 1945**)
- BOLT**, Bruce Alan, Ph.D., Department of Applied Mathematics, University of Sydney. (1956 ; P3)
- BOOKER**, Frederick William, D.Sc., Government Geologist, c/o Geological Survey of N.S.W., Mines Department, Sydney. (1951 ; P1)
- BOOTH**, Brian Douglas, Ph.D., 37 Highfield Road, Lindfield. (1954)
- ***BOOTH**, Edgar Harold, M.C., D.Sc., 29 March Street, Bellevue Hill. (1920 ; P9 ; **President 1936**)
- BOSSON**, Geoffrey, M.Sc., Professor of Mathematics, University of New South Wales, Kensington. (1951 ; P2)
- BOSWORTH**, Richard Charles Leslie, D.Sc., Associate Professor, School of Physical Chemistry, University of New South Wales, Kensington. (1939 ; P25 ; **President 1951**)
- BREYER**, Bruno, M.D., Ph.D., Department of Agricultural Chemistry, University of Sydney. (1946 ; P1)
- BRIDGES**, David Somerset, 19 Mount Pleasant Avenue, Normanhurst. (1952)
- ***BRIGGS**, George Henry, D.Sc., 13 Findlay Avenue, Roseville. (1919 ; P1)
- BROWN**, Desmond J., Ph.D., Department of Medical Chemistry, Australian National University, Canberra, A.C.T. (1942)

- BROWNE, Ida Alison, D.Sc., 363 Edgecliff Road, Edgecliff. (1935; P12; **President 1953**)
- *BROWNE, William Rowan, D.Sc., F.A.A., 363 Edgecliff Road, Edgecliff. (1913; P23; **President 1932**)
- BRYANT, Raymond Alfred Arthur, M.E., School of Mechanical Engineering, University of New South Wales, Kensington. (1952)
- BUCHANAN, Gregory Stewart, B.Sc., School of Physical Chemistry, Sydney Technical College. (1947)
- BUCKLEY, Lindsay Arthur, B.Sc., 30 Wattle Street, Killara. (1940)
- BULLEN, Keith Edward, Sc.D., F.R.S., F.A.A., Professor of Applied Mathematics, University of Sydney. (1946; P2)
- BUNCH, Kenneth, Government Analyst, Flat 1, 17 Pacific Street, Manly. (1959)
- BURG, Raymond Augustine, Senior Analyst, Department of Mines, N.S.W.; p.r. 17 Titania Street Randwick. (1960)
- BURROWS, Keith Meredith, B.Sc., Physics Department, University of New South Wales. (1959)
- CAMERON, John Craig, M.A., B.Sc. (Edin.), 15 Monterey Street, Kogarah. (1957)
- CAMPBELL, Ian Gavin Stuart, B.Sc., c/o Wesley Co ege, Prahran, Victoria. (1955)
- *CAREY, Samuel Warren, D.Sc., Professor of Geology, University of Tasmania, Hobart, Tas. (1938; P2)
- CAVILL, George William Kenneth, Ph.D., Associate Professor of Organic Chemistry, University of New South Wales. (1944)
- *CHAFFER, Edric Keith, 27 Warrane Road, Roseville. (1954)
- CHALMERS, Robert Oliver, Australian Museum, College Street, Sydney. (1933; P1)
- CHAMBERS, Maxwell Clark, B.Sc., 58 Spencer Road, Killara. (1940)
- CHAPPELL, Bruce William, B.Sc., Geology Department, Australian National University, Canberra, A.C.T. (1960)
- CHRISTIE, Thelma Isabel, B.Sc., Chemistry School, University of New South Wales. (1953)
- CLANCY, Brian Edward, M.Sc., 21 London Drive, West Wollongong. (1957)
- COHEN, Samuel Bernard, M.Sc., 35 Spencer Road, Killara. (1940)
- COLE, Edward Ritchie, B.Sc., 7 Wolsten Avenue, Turramurra. (1940; P2)
- COLE, Joyce Marie (Mrs.), B.Sc., 7 Wolsten Avenue, Turramurra. (1940; P1)
- COLE, Leslie Arthur, 61 Kissing Point Road, Turramurra. (1948)
- COLEMAN, Patrick Joseph, Ph.D., Geology Department, University of Western Australia, Nedlands, W.A. (1955)
- COLLETT, Gordon, B.Sc., 27 Rogers Avenue, Haberfield. (1940)
- CONAGHAN, Hugh Francis, M.Sc., Senior Analyst, Department of Mines, N.S.W.; p.r. 104 Lancaster Avenue, West Ryde. (1960)
- COOK, Cyril Lloyd, Ph.D., c/o Propulsion Research Laboratories, Box 1424H, G.P.O., Adelaide. (1948)
- COOK, Rodney Thomas, Buckley's Road, Old Toongabbie. (1946)
- *COOMBS, F. A., Bannerman Crescent, Rosebery. (1913; P5)
- CORBETT, Robert Lorimer, c/o Intaglio Pty. Ltd., Sirius Road, Lane Cove. (1933)
- CORTIS-JONES, Beverley, M.Sc., 65 Peacock Street, Seaforth. (1940)
- *COTTON, Leo Arthur, D.Sc., Emeritus Professor, 113 Queen's Parade East, Newport Beach. (1909; P7; **President 1929**)
- CRAIG, David Parker, Ph.D., Department of Theoretical Chemistry, University College, London, W.C.1, England. (1941; P1)
- CRAWFORD, Edwin John, B.E., "Lynwood", Bungalow Avenue, Pymble. (1955)
- CRAWFORD, Ian Andrew, Cr. Barker and O'Grady Streets, Havenview, via Burnie, Tas. (1955)
- *CRESSWICK, John Arthur, 101 Villiers Street, Rockdale. (1921; P1)
- CROFT, James Bernard, 60 Belmont Road, Mosman. (1956)
- CROOK, Keith Alan Waterhouse, Ph.D., Geology Department, Australian National University, Canberra, A.C.T. (1954; P7)
- DADOUR, Anthony, B.Sc., 25 Elizabeth Street, Waterloo. (1940)
- DAVIES, George Frederick, 57 Eastern Avenue, Kingsford. (1952)
- DAY, Alan Arthur, Ph.D., Department of Geology and Geophysics, University of Sydney. (1952)
- DE LEPERVANCHE, Beatrice Joy, 29 Collins Street, Belmore. (1953)
- DENTON, Leslie A., Bunarba Road, Miranda. (1955)
- DIVNICH, George, Engineer Agronom. (Yugoslavia), Engineering Analyst, 7 Highland Avenue, Punchbowl. (1960)
- DONEGAN, Henry Arthur James, M.Sc., c/o Mining Museum, George Street North, Sydney. (1928; **President 1960**)
- DRUMMOND, Heather Rutherford, B.Sc., 2 Gerald Avenue, Roseville. (1950)
- DULHUNTY, John Allan, D.Sc., Department of Geology, University of Sydney. (1937; P16; **President 1947**)
- DURIE, Ethel Beatrix, M.B., Ch.M., Institute of Medical Research, Royal North Shore Hospital, St. Leonards. (1955)
- DWYER, Francis P. J., D.Sc., F.A.A. Professor of Biological Inorganic Chemistry, Australian National University, Canberra, A.C.T. (1934; P62)
- EADE, Ronald Arthur, Ph.D., School of Organic Chemistry, University of New South Wales. (1945)
- EDGAR, Joyce Enid (Mrs.), B.Sc., 22 Slade Avenue, Lindfield. (1951)
- EDGEELL, Henry Stewart, Ph.D., Co., Iranian Oil Exploration and Producing Co., Masjid-i-Sulaiman, via Abadan, Iran. (1950)
- ELKIN, Adolphus Peter, Ph.D., Emeritus Professor, 15 Norwood Avenue, Lindfield. (1934; P2; **President 1940**)
- ELLISON, Dorothy Jean, M.Sc., 45 Victoria Street, Roseville (1949)
- EMMERTON, Henry James, B.Sc., 37 Wangoola Street, East Gordon. (1940)
- *ESDAILE, Edward William, 42 Hunter Street, Sydney. (1908)
- EVANS, Silvanus Gladstone, 6 Major Street, Coogee. (1935)
- FALLON, Joseph James, 1 Coolong Road, Vacluse. (1950)
- FISHER, Robert, B.Sc., 3 Sackville Street, Maroubra. (1940)
- FLEISCHMANN, Arnold Walter, 8/25 Guilfoyle Avenue, Double Bay. (1956)
- FLETCHER, Harold Oswald, M.Sc., The Australian Museum, College Street, Sydney. (1933)
- FORMAN, Kenn P., c/o 52 Pitt Street, Sydney. (1932)

- FREEMAN, Hans Charles, Ph.D., 43 Newcastle Street, Rose Bay. (1950)
- FRENCH, Oswald Raymond, 66 Nottinghill Road, Lidcombe. (1951)
- FRIEND, James Alan, Ph.D., Department of Chemistry, University of Tasmania, Hobart, Tas. (1944; P2)
- FURST, Hellmut Friedrich, D.M.D. (Hamburg), 158 Bellevue Road, Bellevue Hill. (1945)
- FYNN, Anthony Gerard, B.Sc., Director, Riverview College Observatory, Riverview, N.S.W. (1959)
- GALLOWAY, Malcolm Charles, B.B., B.Sc., Geologist, 17 Johnson Street, Chatswood. (1960)
- GARAN, Teodar, c/o Geology Branch, Warragamba Dam, N.S.W. (1952)
- GARRETTY, Michael Duhan, D.Sc., "Surrey Lodge", Mitcham Road, Mitcham, Victoria. (1935; P2)
- GASCOIGNE, Robert Mortimer, Ph.D., Department of Organic Chemistry, University of New South Wales. (1939; P4)
- GIBSON, Neville Allan, Ph.D., 103 Bland Street, Ashfield. (1942; P6)
- GIFFEN, James Campbell, B.Sc. (Capetown), 28 Tango Avenue, Dee Why. (1960)
- GILL, Naida Sugden, Ph.D., 45 Neville Street, Marrickville. (1947)
- *GILL, Stuart Frederic, 45 Neville Street, Marrickville. (1947)
- GLASSON, Kenneth Roderick, B.Sc., 70 Beecroft Road, Beecroft. (1948)
- GOLDING, Henry George, M.Sc., School of Mining Engineering and Applied Geology, University of New South Wales. (1953; P4)
- GOLDSTONE, Charles Lillington, B.Agr.sc., University of New South Wales. (1951)
- GORDON, William Fraser, B.Sc. (1949)
- GRAHAME, Mervyn Ernest, B.A., Schoolteacher, 161 Parry Street, Hamilton, N.S.W. (1959)
- GRAY, Charles Alexander Menzies, B.E., Professor of Engineering, University of Malaya, Malaya (1948; P1)
- GRAY, Noel Mackintosh, B.Sc., 6 Twenty-fourth Street, Warragamba Dam, N.S.W. (1952)
- GRIFFIN, Russell John, B.Sc., c/o Department of Mines, Sydney. (1952)
- GRIFFITH, James Langford, M.Sc., School of Mathematics, University of New South Wales. (1952; P12; **President 1958**)
- GRODEN, Charles Mark, M.Sc., School of Mathematics, University of New South Wales. (1957; P2)
- GUTMANN, Felix, Ph.D., University of New South Wales. (1946; P1)
- HALL, Norman Frederick Blake, M.Sc., 15A Wharf Road, Longueville. (1934)
- HAMPTON, Edward John William, 1 Hunter Street, Waratah, N.S.W. (1949)
- HANCOCK, Harry Sheffield, M.Sc., 21 Constitution Road, Dulwich Hill. (1955).
- HANLON, Frederick Noel, B.Sc., 4 Pearson Avenue, Gordon. (1940; P14; **President 1957**)
- HARPER, Arthur Frederick Alan, M.Sc., National Standards Laboratory, University Grounds, City Road, Chippendale. (1936; P1; **President 1959**)
- HARRIS, Clive Melville, Ph.D., School of Inorganic Chemistry, University of New South Wales. (1948; P6)
- HARRISON, Ernest John Jasper, B.Sc., c/o N.S.W. Geological Survey, Mines Department, Sydney. (1946)
- HAWKINS, Cedric Arthur, B.Sc.Agr., Chemists' Branch, N.S.W. Department of Agriculture, Sydney. (1956; P3)
- *HAYES, Daphne (Mrs.), B.Sc., 98 Lang Road, Centennial Park. (1943)
- HEARD, George Douglas, B.Sc., 17 Hall Road, Hornsby. (1951)
- HIGGS, Alan Charles, c/o Colonial Sugar Refining Co. Ltd., Building Material Division, 1-7 Bent Street, Sydney. (1945)
- HILL, Dorothy, D.Sc., F.A.A., Department of Geology, University of Queensland, St. Lucia, Brisbane (1938; P6)
- HOGARTH, Julius William, B.Sc., University House, Canberra, A.C.T. (1948; P6)
- HOLM, Thomas John, 524 Wilson Street, Redfern. (1952)
- HORNE, Allan Richard, 7 Booralee Street, Botany. (1960)
- HOSKINS, Bernard Foster, B.Sc., 227 Waterloo Road, Greenacre. (1959)
- HUMPHRIES, John William, B.Sc., Physicist, National Standards Laboratory, University Grounds, City Road, Chippendale. (1959)
- *HYNES, Harold John, D.Sc.Agr., Director, N.S.W. Department of Agriculture, Sydney. (1923; P3)
- IREDALE, Thomas, D.Sc., Chemistry Department, University of Sydney. (1943)
- JAEGER, John Conrad, D.Sc., F.A.A., Geophysics Department, Australian National University Canberra, A.C.T. (1942; P1)
- JAMIESON, Helen Campbell, 3 Hamilton Street, Coogee. (1951)
- JENKINS, Thomas Benjamin Huw, Ph.D., Department of Geology and Geophysics, University of Sydney. (1956)
- JONES, James Rhys, 25 Boundary Road, Mortdale. (1959)
- JOPLIN, Germaine Anne, D.Sc., Geophysics Department, Australian National University, Canberra, A.C.T. (1935; P8)
- KEANE, Austin, Ph.D., Australian Atomic Energy Commission, Lucas Heights, N.S.W. (1955; P3)
- KELLY, Caroline Tennant (Mrs.), Dip.Anthr., "Silvermists", Robertson, N.S.W. (1935)
- KEMP, William Ronald Grant, B.Sc., Physicist, 16 Fig Tree Street, Lane Cove. (1960)
- *KENNY, Edward Joseph, 65 Park Avenue, Ashfield. (1924; P1)
- KIMBLE, Frank Oswald, 31 Coronga Crescent, Killara. (1948)
- KIMBLE, Jean Annie, B.Sc., 383 Marrickville Road, Marrickville. (1943)
- *KIRCHNER, William John, B.Sc., 18 Lyne Road, Cheltenham. (1920)
- KNIGHT, Oscar Le Maistre, B.E., 10 Mildura Street, Killara. (1948).
- KOCH, Leo E., D.Phil.Habil., School of Mining Engineering and Applied Geology, University of New South Wales. (1948)
- KRYSKO v. TRYST, Moiren, National Standards Laboratory, University Grounds, City Road, Chippendale. (1959)
- LAMBETH, Arthur James, B.Sc., "Talanga", Picton Road, Douglas Park, N.S.W. (1939; P3)
- LANG, Thomas Arthur, M.C.E., Bechtel Corporation, 537 Market Street, San Francisco 5, California, U.S.A. (1955)
- LAWRENCE, Laurence James, Ph.D., Associate Professor, School of Mining Engineering and Applied Geology, University of New South Wales. (1951; P1)

- LAWRENCE, Peter, M.A., Ph.D., Department of Anthropology, University of Western Australia, Nedlands, W.A. (1959)
- LEACH, Stephen Laurence, B.Sc., c/o Taubman's Industries Ltd., Box 82A, P.O., North Sydney. (1936)
- LEECHMAN, Frank, 51 Willoughby Street, Kirribilli. (1957)
- LE FEVRE, Raymond James Wood, D.Sc., F.R.S., F.A.A., Professor of Chemistry, University of Sydney. (1947; **President 1961**)
- LEMBERG, Max Rudolph, D.Phil., F.R.S., F.A.A., Assistant Director, Institute of Medical Research, Royal North Shore Hospital, St. Leonards. (1936; P3; **President 1955**)
- LESLIE, Rupert Thomas, M.A., Ph.D., Statistician, National Standards Laboratory, University Grounds, City Road, Chippendale. (1960)
- *LIONS, Francis, Ph.D., Department of Chemistry, University of Sydney. (1929; P56; **President 1946**)
- LIONS, Jean Elizabeth (Mrs.), B.Sc., 160 Alt Street, Haberfield. (1940)
- LLOYD, James Charles, B.Sc., c/o N.S.W. Geological Survey, Mines Department, Sydney. (1947)
- LOCKWOOD, William Hutton, B.Sc., c/o Institute of Medical Research, Royal North Shore Hospital, St. Leonards. (1940; P1)
- LOVERING, John Francis, Ph.D., Department of Geophysics, Australian National University, Canberra, A.C.T. (1951; P3)
- LOW, Angus Henry, Ph.D., School of Mathematics, University of New South Wales. (1950; P1)
- LOWENTHAL, Gerhard, M.Sc., 43 Hinkler Street, Maroubra. (1959)
- LYONS, Lawrence Ernest, Ph.D., Chemistry Department, University of Sydney. (1948; P2)
- MACCOLL, Allan, M.Sc., Department of Chemistry, University College, Gower Street, London, W.C.1, England. (1939; P4)
- MCCARTHY, Frederick David, Dip.Anthr., Australian Museum, College Street, Sydney. (1949; P1; **President 1956**)
- MCCOY, William Kevin, c/o Mr. A. J. McCoy, 23 Victoria Road, Pennant Hills. (1943)
- MCCULLAGH, Morris Behan, 23 Wallaroy Road, Edgecliff. (1950)
- McELROY, Clifford Turner, Ph.D., M.Sc., "Bithongabel", Bedford Road, Woodford, N.S.W. (1949; P2)
- McGREGOR, Gordon Howard, 4 Maple Avenue, Pennant Hills. (1940)
- McKAY, Maxwell Herbert, M.A., School of Mathematics, University of New South Wales. (1956; P1)
- McKERN, Howard Hamlet Gordon, M.Sc., Senior Chemist, Museum of Applied Arts and Sciences, Harris Street, Broadway, Sydney. (1943; P9)
- McMAHON, Patrick Reginald, Ph.D., Professor of Wool Technology, University of New South Wales. (1947)
- McNAMARA, Barbara Joyce (Mrs.), M.B., B.S., 167 John Street, Singleton, N.S.W. (1943)
- MAGEE, Charles Joseph, D.Sc.Agr., Division of Science Services, N.S.W. Department of Agriculture, Victoria Road, Rydalmere. (1947; P1; **President 1952**)
- MALES, Pamela Ann, 13 Gelding Street, Dulwich Hill. (1951)
- MANDER-JONES, Burnett, M.Sc., 2 St. Giles Avenue, Greenwich. (1960; P1)
- MARSHALL, Charles Edward, D.Sc., Professor of Geology, University of Sydney. (1949; P1)
- MARSDEN, Joan Audrey, 203 West Street, Crows Nest. (1955)
- MAZE, William Harold, M.Sc., Deputy Principal, University of Sydney. (1935; P1)
- MEARES, Harry John Devenish, Technical Librarian, Colonial Sugar Refining Co. Ltd., Box 483, G.P.O., Sydney. (1949)
- MEGGITT, Mervyn John, M.A., Lecturer, Department of Anthropology, University of Sydney. (1959)
- *MELDRUM, Henry John, B.Sc., 116 Sydney Road, Fairlight. (1912)
- MELLOR, David Paver, D.Sc., Professor of Inorganic Chemistry, University of New South Wales. (1929; P25; **President 1941**)
- MIDDLEHURST, Jack, M.Sc., Physicist, National Standards Laboratory, University Grounds, City Road, Chippendale. (1960)
- MILLER, James, B.Sc., 35 Angus Avenue, Waratah West, N.S.W. (1959)
- MILLERSHIP, William, M.Sc., 18 Courallie Avenue, Pymble. (1940)
- MINTY, Edward James, B.Sc., Cooyong Road, Terrey Hills, N.S.W. (1951; P1)
- *MORRISON, Frank Richard, 4 Mona Street, Wahroonga. (1922; P34; **President 1950**)
- MORRISEY, Matthew John, M.B., B.S., 46 Auburn Street, Parramatta. (1941)
- MORT, Francis George Arnot, 110 Green's Road, Fivedock. (1934)
- MOSHER, Kenneth George, B.Sc., c/o Joint Coal Board, 66 King Street, Sydney. (1948)
- MOSS, Francis John, M.B., B.S., 70 Victoria Street, West Pennant Hills. (1955)
- MOYE, Daniel George, B.Sc., Chief Geologist, c/o Snowy Mountains Hydro Electric Authority, Cooma, N.S.W. (1944)
- MULHOLLAND, Charles St. John, B.Sc., Under-Secretary, Mines Department, Sydney. (1946)
- *MURPHY, Robert Kenneth, Dr.Ing.Chem., 68 Pindari Avenue, North Mosman. (1915)
- MURRAY, James Kenneth, B.Sc., Broken Hill, N.S.W. (1951)
- MURRAY, Patrick Desmond Fitzgerald, D.Sc., F.A.A., Zoology Department, University of New England, Armidale, N.S.W. (1950)
- MUTTON, Ann Ruth, B.Sc., 8 Beta Road, Lane Cove. (1959)
- NASHAR, Beryl, Ph.D., 23 Morris Street, Mayfield West, 2N, N.S.W. (1946; P2)
- NAYLOR, George Francis Kinh, Ph.D., Department of Psychology and Philosophy, University of Queensland, Brisbane. (1930; P7)
- *NEUHAUS, John William George, 32 Bolton Street, Guildford. (1943)
- NEWMAN, Ivor Vickery, Ph.D., Botany Department, University of Sydney. (1932)
- NOAKES, Lyndon Charles, B.A., British Commonwealth Geological Liaison Office, Africa House, Kingsway, London, W.C.2, England. (1945; P1)
- *NOBLE, Robert Jackson, Ph.D., 32A Middle Harbour Road, Lindfield. (1920; P4; **President 1934**)
- NYHOLM, Ronald Sydney, D.Sc., F.R.S., Professor of Inorganic Chemistry, University College, Gower Street, London, W.C.1, England. (1940; P26; **President 1954**)
- OLD, Adrian Noel, B.Sc.Agr., 4 Springfield Avenue, Potts Point. (1947)

- OXENFORD, Reginald Augustus, B.Sc., 15 Victoria Street, Grafton. (1950)
- PACKHAM, Gordon Howard, Ph.D., Department of Geology and Geophysics, University of Sydney. (1951; P3)
- *PENFOLD, Arthur Ramon, Flat 40, 3 Greenknowe Avenue, Potts Point. (1920; P82; **President 1935**)
- PERRY, Hubert Roy, B.Sc., 74 Woodbine Street, Bowral, N.S.W. (1948)
- PHILLIPS, Marie Elizabeth, Ph.D., Soils Conservation Section, S.M.H.E.A., Cooma, N.S.W.; p.r. 4 Morella Road, Clifton Gardens. (1938)
- PHIPPS, Charles Verling Gayer, Ph.D., Department of Geology and Geophysics, University of Sydney. (1960)
- PICKERING, William Frederick Joseph, Ph.D., Division of Science, Newcastle University College, Tighes Hill. (1959)
- PINWILL, Norman, B.A., The Scots College, Victoria Road, Bellevue Hill. (1946)
- POGGENDORFF, Walter Hans George, B.Sc.Agr., Chief, Division of Plant Industry, N.S.W. Department of Agriculture, Sydney. (1949)
- *POWELL, Charles Wilfred Roberts, "Wansfell", Kirkoswald Avenue, Mosman. (1921; P2)
- POWELL, John Wallis, c/o Foster Clark (Aust.) Ltd., 17 Thurlow Street, Redfern. (1938)
- PRICE, William Lindsay, B.Sc., School of Physics, Sydney Technical College, Sydney. (1927)
- PRIDDLE, Raymond Arthur, B.E., 7 Rawson Crescent, Pymble. (1956)
- PROKHOVNIK, Simon Jacques, B.Sc., School of Mathematics, University of New South Wales. (1956; P2)
- *PROUD, John Seymour, B.E., Finlay Road, Turramurra. (1945)
- PUTTOCK, Maurice James, B.Sc. (Eng.), A.Inst.P., Principal Research Officer, C.S.I.R.O., Sydney. p.r. 2 Montreal Avenue, Killara. (1960)
- PYLE, John Herbert, B.Sc., Analyst, Mines Department, Sydney. (1958)
- *QUODLING, Florrie Mabel, B.Sc., Geology Department, University of Sydney. (1935; P3)
- RADE, Janis, M.Sc., Box 28A, 601 St. Kilda Road, Melbourne. (1953; P4)
- *RAGGATT, Harold George, C.B.E., D.Sc., F.A.A., Secretary, Department of National Development, Acton, Canberra, A.C.T. (1922; P8)
- RAMM, Eric John, Experimental Officer, Australian Atomic Energy Commission, Research Establishment, Lucas Heights, N.S.W. (1959)
- *RANCLAUD, Archibald Boscawen Boyd, B.E., 79 Frederick Street, Merewether, N.S.W. (1949; P3)
- RAYNER, Jack Maxwell, B.Sc., Director, Bureau of Mineral Resources, Canberra, A.C.T. (1931; P1)
- REICHEL, Alex, M.Sc., School of Mathematics, University of New South Wales. (1957; P3)
- REUTER, Fritz Henry, Ph.D., Associate Professor of Food Technology, University of New South Wales. (1947)
- RITCHIE, Arthur Sinclair, Department of Mineralogy and Geology, Newcastle University College Newcastle. (1947; P2)
- RITCHIE, Ernest, D.Sc., Chemistry Department, University of Sydney. (1939; P19)
- ROBBINS, Elizabeth Marie (Mrs.), M.Sc., Waterloo Road, North Ryde. (1939; P3)
- ROBERTS, Herbert Gordon, 3 Hopetoun Street, Hurlstone Park. (1957)
- ROBERTSON, William Humphrey, B.Sc., c/o Sydney Observatory, Sydney. (1949; P16)
- ROBINSON, David Hugh, 12 Robert Road, West Pennant Hills. (1951)
- ROSENBAUM, Sidney, 23 Strickland Avenue, Lindfield. (1940)
- ROSENTHAL-SCHNEIDER, Ilse, Ph.D., 48 Cambridge Avenue, Vaucluse. (1948)
- ROSS, Victoria (Mrs.), B.Sc. (Hons.), 26 Gold Street, Blakehurst. (1960)
- ROUNTREE, Phyllis Margaret, D.Sc., Royal Prince Alfred Hospital, Sydney. (1945)
- RYAN, D'Arcy James, B.A., B.Litt., Anthropologist, 3 Ormond Street, Bondi. (1959)
- *SCAMMELL, Rupert Boswood, B.Sc., 10 Buena Vista Avenue, Clifton Gardens. (1920)
- SCHOLER, Harry Albert Theodore, M.Eng., Civil Engineer, c/o Harbours and Rivers Branch, Public Works Department, N.S.W., cr. Bridge and Phillip Streets, Sydney. (1960)
- SEE, Graeme Thomas, B.Sc., School of Mining Engineering and Applied Geology, University of New South Wales. (1949)
- SELBY, Edmond Jacob, Box 175D, G.P.O., Sydney. (1933)
- *SHARP, Kenneth Raeburn, B.Sc., c/o S.M.H.E.A., Cooma, N.S.W. (1948)
- SHERRARD, Kathleen Margaret (Mrs.), M.Sc., 43 Robertson Road, Centennial Park. (1936; P5)
- SHERWOOD, Arthur Alfred, B.Sc. (Eng.), c/o Department of Mechanical Engineering, University of Sydney. p.r. 48 David Street, Greenacre. (1959; P1)
- SIMMONS, Lewis Michael, Ph.D., c/o The Scots College, Victoria Road, Bellevue Hill. (1945; P3)
- SIMONETT, David Stanley, Ph.D., Assistant Professor of Geography, University of Kansas, Lawrence, Kansas, U.S.A. (1948; P3)
- SIMPSON, John Kenneth Moore, "Browie", Old Castle Hill Road, Castle Hill. (1943)
- SIMS, Kenneth Patrick, B.Sc., 24 Catherine Street, St. Ives. (1950; P8)
- SLADE, George Hermon, B.St., "Raiatea", Oyama Avenue, Manly. (1933)
- SLADE, Milton John, B.Sc., 12 Dobie Street, Grafton. (1952)
- SMITH, Eric Brian Jeffcoat, D.Phil., 74 Webster Street, Nedlands, W.A. (1940)
- SMITH, Roger Albert Alfred, 62 Budyan Road, Gray's Point. (1960)
- SMITH-WHITE, William Broderick, M.A., Associate Professor, Department of Mathematics, University of Sydney. (1947; P2)
- SOMERVILLE, Jack Murielle, M.A., D.Sc., Department of Physics, University of New England, Armidale, N.S.W. (1959)
- *SOUTHEE, Ethelbert Ambrook, O.B.E., M.A., Trellawney Street, Eastwood. (1919)
- SPARROW, Gerald William Alfred, B.Sc., Geography Department, University of Queensland, St. Lucia, Brisbane. (1958)
- STANTON, Richard Limon, Ph.D., Geology Department, University of New England, Armidale. (1949; P2)
- STAPLEDON, David Hiley, B.Sc., c/o Engineering Geology Branch, S.M.H.E.A., Cooma, N.S.W. (1954)
- *STEPHEN, Alfred Ernest, c/o Box 1158HH, G.P.O., Sydney. (1916)
- *STEPHENS, Frederick G. N., M.B., Ch.M., 133 Edinburgh Road, Castlecrag. (1914)

- STEPHENS, James Norrington, M.A. (Cantab.), 40 Pymble Avenue, Pymble. (1959)
- STEVENS, Neville Cecil, Ph.D., Geology Department, University of Queensland, Brisbane. (1948; P5)
- *STONE, Walter George, 26 Rosslyn Street, Bellevue Hill. (1916; P1)
- STRUSZ, Desmond Leslie, B.Sc., Department of Geology, University of Sydney. p.r. Flat 3, 2a High Street, Randwick. (1960; P1).
- STUNTZ, John, B.Sc., 511 Burwood Road, Belmore. (1951)
- *SUTHERLAND, George Fife, A.R.C.Sc., 47 Clanwilliam Street, Chatswood. (1919)
- *SUTTON, Harvey, O.B.E., M.D., 27 Kent Road, Rose Bay. (1920)
- SWANSON, Thomas Baikie, M.Sc., c/o Technical Service Department, I.C.I.A.N.Z., Box 1911, G.P.O., Melbourne. (1941; P2)
- SWINBOURNE, Ellice Simmons, Ph.D., 69 Peacock Street, Seaforth. (1948)
- *TAYLOR, Brigadier Harold B., M.C., D.Sc., 12 Wood Street, Manly. (1915; P3)
- THEW, Raymond Farly, 88 Braeside Street, Wahroonga. (1955)
- THOMAS, Penrhyn Francis, Suite 22, 3rd Floor, 29 Market Street, Sydney. (1952)
- THOMSON, David John, B.Sc., Geologist, 61 The Bulwark, Castlecrag. (1956)
- THOMSON, Vivian Endel, B.Sc., c/o Snowy Mountains Hydro Electric Authority, Geological Laboratory, Scientific Services Division, Cooma North, N.S.W. (1960)
- TOMPKINS, Denis Keith, M.Sc., c/o Geology Department, University of Sydney, Sydney. (1954; P1)
- TICHAUER, Erwin R., D.Sc.(Tech.), Dipl.Ing., Department of Industrial Engineering, University of New South Wales. (1960)
- TOW, Aubrey James, M.Sc., c/o Community Hospital, Canberra, A.C.T. (1940)
- TREBECK, Prosper Charles Brian, 54 Great North Road, Fivedock. (1949)
- UNGAR, Andrew, Dipl.Ing., 6 Ashley Grove, Gordon. (1952)
- VALLANCE, Thomas George, Ph.D., Geology Department, University of Sydney. (1949; P1)
- VAN DIJK, Dirk Cornelius, D.Sc.Agr., 2 Lobelia Street, O'Connor, Canberra, A.C.T. (1958)
- VEEVERS, John James, Ph.D., Bureau of Mineral Resources, Canberra, A.C.T. (1953)
- VERNON, Ronald Holden, M.Sc., c/o Geology Department, University of Sydney. (1958)
- *VICARS, Robert, "Yallambee", The Crescent, Cheltenham. (1921)
- VICKERY, Joyce Winifred, D.Sc., 17 The Promenade, Cheltenham. (1935)
- VOISEY, Alan Heywood, D.Sc., Professor of Geology and Geography, University of New England. (1933; P10)
- *VONWILLER, Oscar U., B.Sc., Emeritus Professor, "Silvermists", Robertson, N.S.W. (1903; P10; **President 1940**)
- WALKER, Donald Francis, 13 Beauchamp Avenue, Chatswood. (1948)
- WALKER, Patrick Hilton, M.Sc.Agr., Research Officer, C.S.I.R.O., Division of Soils. p.r. 3 Miller Street, O'Connor, Canberra, A.C.T. (1956; P3)
- *WALKOM, Arthur Bache, D.Sc., 45 Nelson Road, Killara. (1919 and previous membership 1910-1913; P2; **President 1943**)
- WARD, Judith (Mrs.), B.Sc., 50 Bellevue Parade, New Town, Hobart, Tasmania. (1948)
- *WARDLAW, Hy. Sloane Halcro, D.Sc., 71 McIntosh Street, Gordon. (1913; P5; **President 1939**)
- *WATERHOUSE, Lionel Lawry, B.E., 42 Archer Street, Chatswood. (1919; P1)
- *WATERHOUSE, Walter L., C.M.G., M.C., D.Sc.Agr., F.A.A., "Hazelmere", Chelmsford Avenue, Lindfield. (1919; P7; **President 1937**)
- *WATT, Sir Robert Rickie, M.A., Emeritus Professor, 5 Gladswood Gardens, Double Bay. (1911; P1; **President 1925**)
- *WATTS, Arthur Spencer, "Araboono", Glebe Street, Randwick. (1921)
- WENHAM, Russell George, B.Sc., B.E., 17 Fortescue Street, Bexley North. (1960)
- WEST, Norman William, B.Sc., c/o Department of Main Roads, Sydney. (1954)
- WESTHAIMER, Gerald, Ph.D., c/o Perpetual Trustee Co. Ltd., 33 Hunter Street, Sydney. (1949)
- WHITLEY, Alice, Ph.D., 39 Belmore Road, Burwood. (1951)
- WHITWORTH, Horace Francis, M.Sc., Mining Museum, Sydney. (1951; P4)
- WILKINS, Coleridge Anthony, M.Sc. (N.Z.), Flat 2, 10 Heath Street, Randwick.
- WILLIAMS, Benjamin, 12 Cooke Way, Epping. (1949)
- WILLIAMSON, William Harold, M.Sc., 6 Hughes Avenue, Ermington. (1949)
- WILSON, Peter Robert, B.A., M.Sc., Lecturer in Applied Mathematics, University of Sydney. (1959)
- WOOD, Clive Charles, Ph.D., B.Sc., c/o S.M.H.E.A., Cooma, N.S.W. (1954)
- WOOD, Harley Weston, M.Sc., Government Astronomer, Sydney Observatory, Sydney. (1936; P14; **President 1949**)
- WYLIE, Russell George, Ph.D., M.Sc., Physicist, 11 Church Street, Randwick. (1960)
- WYNN, Desmond Watkin, B.Sc., c/o Mines Department, Sydney. (1952)

Associates

- BOLT, Beverley (Mrs.), M.Sc., 3/17 Alexander Street, Coogee. (1959)
- DANCE, Ian G., 22 The Promenade, Cheltenham. (1960)
- DENTON, Norma, 97 Bunarba Road, Miranda. (1959)
- DONEGAN, Elizabeth (Mrs.), 18 Hillview Street, Sans Souci. (1956)
- GRIFFITH, Elsie A. (Mrs.), 9 Kanoona Street, Caringbah. (1956)
- McGLYNN, John Albert, 34 Highlands Avenue, Gordon. (1960)
- SMITH, Glennie Forbes, B.Sc., 2 Mars Road, Lane Cove. (1958)
- STEVENS, Eric Leslie, 99 Trafalgar Street, Stanmore. (1961)

Obituary, 1960-61

The Rt. Hon. Viscount Dunrossil (1960)
 Charles Edward Fawsitt (1909)
 Neil Ernest Goldsworthy (1947)
 Herbert Richard Harrington (1934)

Daryl Robert O'Dea (1951)
 Hugh Raymond Guy Poate (1919)
 Henry Priestley (1918)
 Sir Harold Spencer-Jones (1946)

Medals, Memorial Lectureships and Prizes awarded by The Society

The James Cook Medal

A bronze medal awarded for outstanding contributions to science and human welfare in and for the Southern Hemisphere.

1947	J. C. Smuts (South Africa)	1953	Sir D. Rivett (Australia)
1948	B. A. Houssay (Argentina)	1954	Sir F. M. Burnet (Australia)
1950	Sir N. H. Fairley (U.K.)	1955	A. P. Elkin (Australia)
1951	N. McA. Gregg (Australia)	1956	Sir I. Clunies Ross (Australia)
1952	W. L. Waterhouse (Australia)	1959	A. Schweitzer (Fr. Eq. Africa)

The Walter Burfitt Prize

A bronze medal and money prize of £75 awarded at intervals of three years to the worker in pure and applied science, resident in Australia or New Zealand, whose papers and other contributions published during the preceding six years are deemed of the highest scientific merit, account being taken only of investigations described for the first time, and carried out by the author mainly in those Dominions. Established as a result of generous gifts to the Society of Dr. and Mrs. W. F. Burfitt.

1929	N. D. Royle (Medicine)	1947	J. C. Jaeger (Mathematics)
1932	C. H. Kellaway (Medicine)	1950	D. F. Martyn (Ionospheric Physics)
1935	V. A. Bailey (Physics)	1953	K. E. Bullen (Geophysics)
1938	F. M. Burnet (Medicine)	1956	J. C. Eccles (Medicine)
1941	F. W. Whitehouse (Geology)	1959	F. J. Fenner (Medicine)
1944	H. L. Kesteven (Medicine)		

The Clarke Medal

Awarded from time to time for distinguished work in the Natural Sciences done in or on the Australian Commonwealth and its territories; the person to whom the award is made may be resident in the Australian Commonwealth or its territories or elsewhere. Established by the Society soon after the death of the Rev. W. B. Clarke in appreciation of his character and services "as a learned colonist, a faithful minister of religion, and an eminent scientific man".

The recipients from 1878 to 1929 were given in this Journal, vol. 89, p. xv, 1955.

1930	L. Keith Ward (Geology)	1947	H. L. Clark (Botany)
1931	R. J. Tillyard (Entomology)	1948	A. B. Walkom (Palaeobotany)
1932	F. Chapman (Palaeontology)	1949	Rev. H. M. R. Rupp (Botany)
1933	W. G. Woolnough (Geology)	1950	I. M. Mackerras (Entomology)
1934	E. S. Simpson (Mineralogy)	1951	F. L. Stillwell (Geology)
1935	G. W. Card (Geology)	1952	J. G. Wood (Botany)
1936	Sir Douglas Mawson (Geology)	1953	A. J. Nicholson (Entomology)
1937	J. T. Jutson (Geology)	1954	E. de C. Clarke (Geology)
1938	H. C. Richards (Geology)	1955	R. N. Robertson (Botany)
1939	C. A. Sussmilch (Geology)	1956	O. W. Tiegs (Zoology)
1941	F. Wood Jones (Zoology)	1957	Irene Crespin (Geology)
1942	W. R. Browne (Geology)	1958	T. G. B. Osborn (Botany)
1943	W. L. Waterhouse (Botany)	1959	T. Iredale (Zoology)
1944	W. E. Agar (Zoology)	1960	A. B. Edwards (Geology)
1945	W. N. Benson (Geology)	1961	C. A. Gardner (Botany)
1946	J. M. Black (Botany)		

The Society's Medal

A bronze medal awarded from 1884 until 1896 for published papers. The Award was revived in 1943 for scientific contributions and services to the Society.

1884	W. E. Abbott	1948	W. L. Waterhouse (Agriculture)
1886	S. H. Cox	1949	A. P. Elkin (Anthropology)
1887	J. Seaver	1950	O. U. Vonwiller (Physics)
1888	Rev. J. E. Tenison-Woods	1951	A. R. Penfold (Applied Chemistry)
1889	T. Whitelegge	1953	A. B. Walkom (Palaeobotany)
	Rev. J. Mathew	1954	D. P. Mellor (Chemistry)
1891	Rev. J. Milne Curran	1955	W. G. Woolnough (Geology)
1892	A. G. Hamilton	1956	W. R. Browne (Geology)
1894	J. V. De Coque	1957	R. C. L. Bosworth (Physical Chemistry)
	R. H. Mathews	1958	F. R. Morrison (Applied Chemistry)
1895	C. J. Martin	1959	Ida A. Browne (Geology)
1896	Rev. J. Milne Curran	1960	T. Griffith Taylor (Geography)
1943	E. Cheel (Botany)		

The Edgeworth David Medal

A bronze medal awarded to Australian research workers under the age of thirty-five years for work done mainly in Australia or its territories, or contributing to the advancement of Australian science.

1948	R. G. Giovanelli (Astrophysics)	1954	E. S. Barnes (Mathematics)
	E. Ritchie (Organic Chemistry)	1955	H. B. S. Womersley (Botany)
1949	T. B. Kiely (Plant Pathology)	1957	J. M. Cowley (Chemical Physics)
1950	R. M. Berndt (Anthropology)		J. P. Wild (Radio Astronomy)
	Catherine H. Berndt (Anthropology)	1958	P. I. Korner (Physiology)
1951	J. G. Bolton (Radio Astronomy)	1960	R. D. Brown (Chemistry)
1952	A. B. Wardrop (Botany)		

Clarke Memorial Lectureship

The lectureship is awarded for the purpose of the advancement of Geology. The practice of publishing the lectures in the Journal began in 1936.

1903	T. W. E. David	1943	H. G. Raggatt
1906	E. W. Skeats (two lectures)	1944	W. H. Bryan
1907	T. W. E. David (two lectures)	1945	E. S. Hills
	W. G. Woolnough	1946	L. A. Cotton
	E. F. Pittman	1947	H. S. Summers
	W. S. Dun	1948	Sir Douglas Mawson
1918	R. J. A. Berry	1949	W. R. Browne
1919	T. W. E. David	1950	F. W. Whitehouse
1936	W. G. Woolnough	1951	A. B. Edwards
1937	H. C. Richards	1953	M. F. Glaessner
1938	C. T. Madigan	1955	R. O. Chalmers
1939	Sir John S. Flett	1957	A. H. Voisey
1940	E. J. Kenny	1959	D. E. Thomas
1941	C. A. Sussmilch	1961	J. A. Dulhunty
1942	E. C. Andrews		

Liversidge Research Lectureship

The lectureship is awarded at intervals of two years for the purpose of encouragement of research in Chemistry. It was established under the terms of a bequest to the Society by Professor Archibald Liversidge. The lectures are published in the Journal.

1931	H. Hey	1950	Hedley R. Marston
1933	W. J. Young	1952	A. L. G. Rees
1940	G. J. Burrows	1954	M. R. Lemberg
1942	J. S. Anderson	1956	G. M. Badger
1944	F. P. Bowden	1958	A. D. Wadsley
1946	L. H. Briggs	1960	R. J. W. Le Fevre
1948	I. Lauder		

Pollock Memorial Lectureship

Sponsored by the University of Sydney and the Royal Society of New South Wales in memory of Professor J. A. Pollock.

1949 T. M. Cherry
1952 H. S. W. Massey

1955 R. v. d. R. Woolley
1959 Sir Harold Jeffreys

The Archibald D. Olle Prize

Awarded from time to time at the discretion of the Council to the member of the Society who has submitted the best paper in any year. Established under the terms of a bequest by Mrs. A. D. Olle.

1956 R. L. Stanton
1958 Alex Reichel

1959 G. Bosson
1960 H. G. Golding

The Society's Money Prize

A prize of £25 awarded for published papers (awarded in 1882 only).

1882 J. Fraser and A. Ross

Section of Geology

CHAIRMAN: L. E. KOCH, D.PHIL.HABIL.; HON. SECRETARY: H. G. GOLDING, M.SC., A.R.C.S.

Abstract of Proceedings, 1960

Five meetings were held during the year 1960. Average attendance was 17 members and visitors.

MARCH 18th (Annual Meeting). Election of Office-bearers: Dr. L. E. Koch was elected Chairman and Mr. H. G. Golding was elected Honorary Secretary of the Section.

(1) *Notes and Exhibits*: Dr. L. J. Lawrence reported the recent discovery, in the oxidized portion of the Broken Hill Lode, of several rare minerals. These included large masses of acanthite, differential thermal analysis of which showed that the inversion from the orthorhombic to the higher temperature isometric form was spontaneous in both directions at 185°C. Quenching failed to arrest reversion. Dr. Lawrence exhibited this acanthite formed by supergene processes and also specimens of the cubic paramorph from the Consols lode formed as hypogene argentite which had reverted to acanthite on cooling. Dr. Lawrence also exhibited specimens of chalcophanite, the first recorded from Broken Hill. Dr. T. G. Vallance commented on the "Big Hole" (Parish of Tallaganda, Co. of St. Vincent), a collapse structure about 2 chains wide and 250 feet deep. The feature, in Upper Devonian arkoses, is no doubt related to subsidence in underlying limestones which appear at the surface a few miles away at Wombeyan Caves. Dr. Vallance also exhibited a hornfels containing ellipsoidal bodies, about one inch across, with concentric structure. The hornfels occurs at a granite contact near the Marble Arch, Moodong Creek, east of the "Big Hole". Mr. H. G. Golding exhibited specimens of contorted damourite schist from the sillimanite quarries south-west of Broken Hill and similar pods from Williamstown, South Australia. Mr. Golding suggested that as well as tectonic control of mineralization some degree of mineral control of local tectonism might be considered as a genetic factor for these occurrences. Dr. Koch referred to the occurrence of diaspore in flakes up to one inch wide and to sillimanite veins cutting "felted" sillimanite rock collected by him from the same Broken Hill locality in 1954. Mrs. K. Sherrard noted the recent discovery by R. Kozlowski in Poland, of Ordovician plant remains in glacial erratics.

(2) *Lecturette*: "Geological Notes from the A.N.Z.A.A.S. Excursions, 1959: Kalgoorlie and Perth-Katanning", by Dr. L. E. Koch. Dr. Koch showed slides of the 2,500 years old Boya granite (S.E. of Perth), dissected by dolerite dykes the age of which was determined to lie between 500 and 700 million years. Dr. Koch exhibited morganite from Londonderry near Coolgardie, allanite from Dale Bridge, achroite from Zamia, and sapphirine-cordierite rocks from Dangin, the last three localities being between 20 and 120 miles east to south-east of Perth.

MAY 20th. Addresses: "Reports on Aspects of Recent Work by Officers of the Geological Survey of New South Wales."

Mr. E. J. Harrison, Acting Government Geologist of New South Wales, reviewed the organization of the Geological Survey. Mr. Harrison also exhibited

some of the geological maps recently printed and shortly to be printed, and referred to the coming issue of the revised New South Wales geological map.

Mr. E. O. Rayner reviewed recent work in the Cobar district and exhibited specimens of stilpnomelane which accompanies the ore, and also fossil fish plates of Famennian age collected by himself and Mr. H. O. Fletcher from the Wuttagoona area, 40 miles north-west of Cobar. Mr. Rayner then referred to recent work on the tin fields at Tingha, Ardlethan and Tallebung. At Tallebung, quartz-cassiterite veins occur in slates containing Caradocian graptolites. Specimens of these graptolites and others from 12 miles north-west of Tallebung, indicating the most north-westerly occurrence of Ordovician rocks confirmed in New South Wales, were exhibited. Mr. Rayner also showed colour slides illustrating his remarks.

Mr. C. L. Adamson spoke on engineering geology and dealt with his recent work at the Ravensworth-Liddell Power Station site. Geological investigation had influenced site selection by eliminating cooling-pond locations the use of which would have resulted in the flooding of known coal reserves or prevented exploitation of an economic seam discovered during exploratory drilling. Mr. Adamson also exhibited specimens of sedimentary rock from Ravensworth which had been fused as a result of burning coal seams, and which formed the subject of a recent paper by Mr. H. F. Whitworth.

Mr. D. W. Wynn discussed his recent survey of the State's gypsum deposits. These are mainly Recent and occupy depressions but some are probably Tertiary and occur as raised deposits along the Darling River and Ana Branch. Aeolian gypsite dunes occur mainly east of the depressions and some secondary consolidation had occurred. All the economic gypsum deposits occur west of longitude 146. Mr. Wynn exhibited a range of specimens and illustrated his remarks with colour slides.

JULY 15th. (1) Address: "Hydrothermal Halloysite 4H₂O from the Muswellbrook District", by Mr. D. Craig. Mr. Craig discussed the genesis of fully hydrated halloysite from a locality near Muwellsbrook. The mineral resulted from hydrothermal reconstitution of metakaolin, the latter having resulted from thermal metamorphism of a clay breccia. Metamorphism was induced by the underground burning of a coal seam, probably fired by a Tertiary intrusion of "picrite-basalt". Concurrent fusion of associated sediments had resulted in assemblages of tridymite-cristobalite-cordierite-mullite and magnetite. With lowering temperature the water driven from surrounding rocks reacted with the metakaolin to produce the halloysite. Mr. Craig exhibited specimens to illustrate his remarks.

(2) *Address*: "Factors Influencing Petroleum Accumulation in Australia", by Mr. J. Cameron. Mr. Cameron first referred to tilted contacts of oil, water and gas which result from artesian conditions. In contrast to oil accumulation in closed structures, under hydrodynamic conditions accumulations in

unclosed structures can occur. Mr. Cameron then outlined methods for the determination of sub-surface pressures, stressing the importance of such data for assessing possible "off-structure" accumulation of oil. In areas lacking orogenic folding, the main structures available for oil accumulation must be depositional. The importance of drape folding and of structures "inherited" from the basement was emphasized. Mr. Cameron exemplified his remarks by reference to the Great Artesian Basin and to the Cobar Shield.

SEPTEMBER 16th. (1) *Exhibit*: Dr. L. E. Koch exhibited large specimens of massive sillimanite of felted texture from a quarry 18 miles west-south-west of Broken Hill. The massive rock is transected by veins of white silky sillimanite over an inch wide, with a partly preferential orientation of the sillimanite fibres normal to the vein walls. Associated platy ilmenite crystals also show a preferential orientation, their plate diameters being roughly normal to the vein walls.

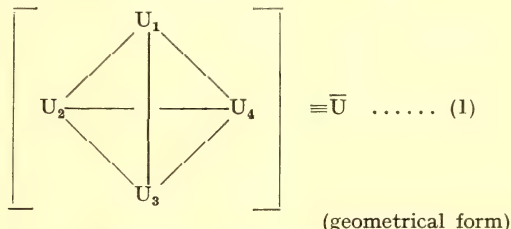
(2) *Address*: "Some Aspects of Overseas Geological Research and Teaching", by Dr. J. A. Dulhunty. Dr. Dulhunty referred to the trend in geological research away from descriptive geology and toward geophysics, geochemistry and nuclear geology.

In undergraduate teaching physiography was being minimized to allow more time for basic science subjects. It had become necessary to think in terms of geology courses of 5 or 6 years duration. Dealing with coal science Dr. Dulhunty said that extended use of coal for the chemical industry depends on elucidating its fundamental characters but research in this field had been disappointing. In the second part of his address Dr. Dulhunty touched on the scenic, physiographic and architectural highlights of his recent travels. Series of slides shown included: Weathering detail of marble, granite and sandstone building-stones in Europe; Aspects of Swiss Alpine physiography; Physiographic and tectonic features of the Mohave Desert and the Grand Canyon, and University Buildings in Europe and America. Dr. Dulhunty also exhibited lavas and a volcanic bomb from the Mohave Desert, limestone from the Rock of Gibraltar, a deformed pebble from the Old Red Sandstone of Britain and other specimens collected during his recent travels.

NOVEMBER 18th. (1) *Exhibits*: Mr. F. Leechman showed a series of colour slides illustrating the topography and surface deposits of opal fields at Coober Pedy, South Australia, and at locations in the extreme south-west of Queensland. Miss P. Males exhibited specimens from Jagersfontein and De Beers Mines, South Africa. These included eclogite, kimberlite and single crystals of chrome-diopside, phlogopite, pyrope and ilmenite. Mr. H. G. Golding exhibited a zoned silica brick from the refractory lining of a glass-melting tank and showed coloured slides of photomicrographs of the tridymite zone.

(2) *Address*: "The Concept-Structure: 'Crystal Symmetry'", by L. E. Koch.

When approaching problems of crystal symmetry empirically, i.e., from observation and measurement of geometrical, physical, structural, etc., features, the following concept structure provides the means for the systematic construction, testing, and evaluation of the hypotheses involved:



or, in its "algebraic" representation:

$$(-U_1 - U_2 - U_3 - U_4) \equiv \bar{U} \dots (2),$$

where U_1 = inversion, U_2 = rotation, U_3 = mirror reflection, and U_4 = translation, and \bar{U} denotes the (unitary) concept of a higher order, i.e., "crystal symmetry". The calculus of composite wholes (embodying the theory of sets, both with and without regard to empirical order of the elements, the theory of relations, and combinatorics), supplemented by other tools of reasoning and calculating embodied in "Finite Mathematics" (Kemeny, 1958), can then immediately be applied to the above concept structure and the relations of its constituent elements.

H. G. GOLDING,
Hon. Secretary, Section of Geology.

Notice to Authors

General. Manuscripts should be addressed to the Honorary Secretaries, Royal Society of New South Wales, Science House, 157 Gloucester Street, Sydney. Two copies of each manuscript are required: the original typescript and a carbon copy.

Papers should be prepared according to the general style adopted in this Journal. They should be as concise as possible, consistent with adequate presentation. Particular attention should be given to clarity of expression and good prose style.

The typescript should be double-spaced, preferably on quarto paper, with generous side margins. Headings should be typed without underlining; if a paper is long, the headings should also be given in a table of contents typed on a separate sheet, for the guidance of the Editor.

The approximate positions of Figures, Plates and Tables should be indicated in the text between parallel ruled lines. Captions of Figures and Plates should be typed on a separate sheet.

The author's institutional or residential address should be given at the conclusion of the paper, the relevant author's initials being attached in brackets to the appropriate address in cases of papers written jointly.

Abstract. An *informative* abstract should be provided at the commencement of each paper for the guidance of readers and for use in abstracting journals.

Tables. Tabular matter should be type-written on separate sheets, arranged for the most economical presentation on the printed page. Column lines should *not* be ruled in. Units of measurement should always be indicated in the headings of the columns or rows to which they apply.

References. References are to be cited in the text by giving the author's name and the year of publication, e.g.: Vick (1934); at the end of the paper they should be arranged alphabetically giving the author's name and initials, the year of publication, the title of the paper (if desired), the abbreviated title of the journal, volume number and pages, thus:

VICK, C. G., 1934. *Astr. Nach.*, 253, 277.

The abbreviated form of the title of this journal is: *J. Proc. Roy. Soc. N.S.W.*

Line Diagrams. Line diagrams should be made with dense black ink on either white bristol board, blue linen or pale-blue ruled graph paper. Tracing paper is unsatisfactory because it is subject to attack by silverfish and also changes its shape in sympathy with the atmospheric humidity. The thickness of lines and the size of letters and numbers should be such as to permit photographic reduction without loss of detail.

Whenever possible dye-line or photographic copies of each diagram should be sent so that the originals need not be sent to referees, thus eliminating possible damage to the diagrams while in the mail.

Photographs. Photographs should be included only where essential, should be glossy, preferably mounted on white card, and should show as much *contrast* as possible. Particular attention should be paid to contrast in photographs of distant scenery and of geological subjects.

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VOLUME 95 1961 PARTS 3 & 4

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Omitted from Part 2, between pages 88-89.

Binder please note.



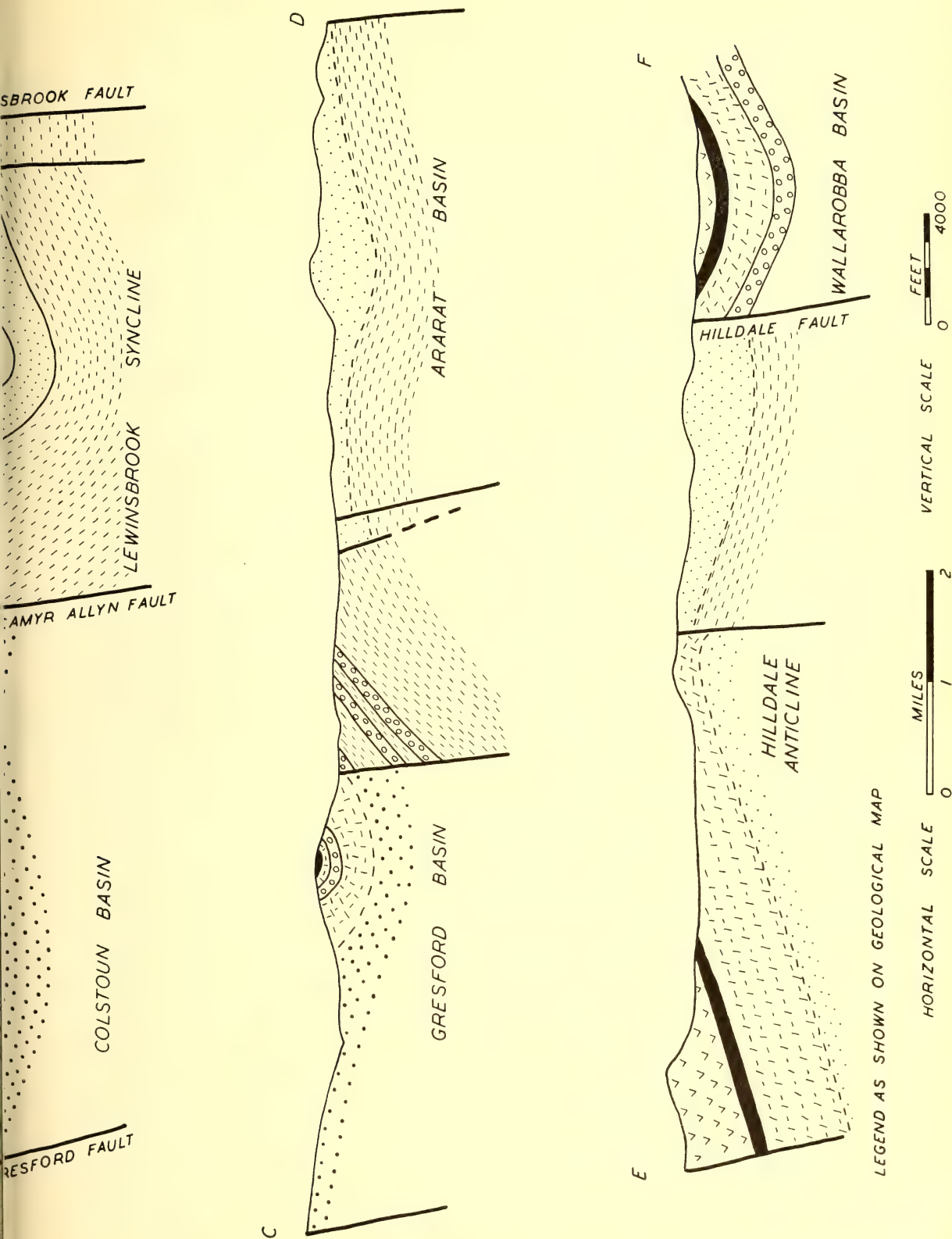


Fig. 3
Geological cross sections

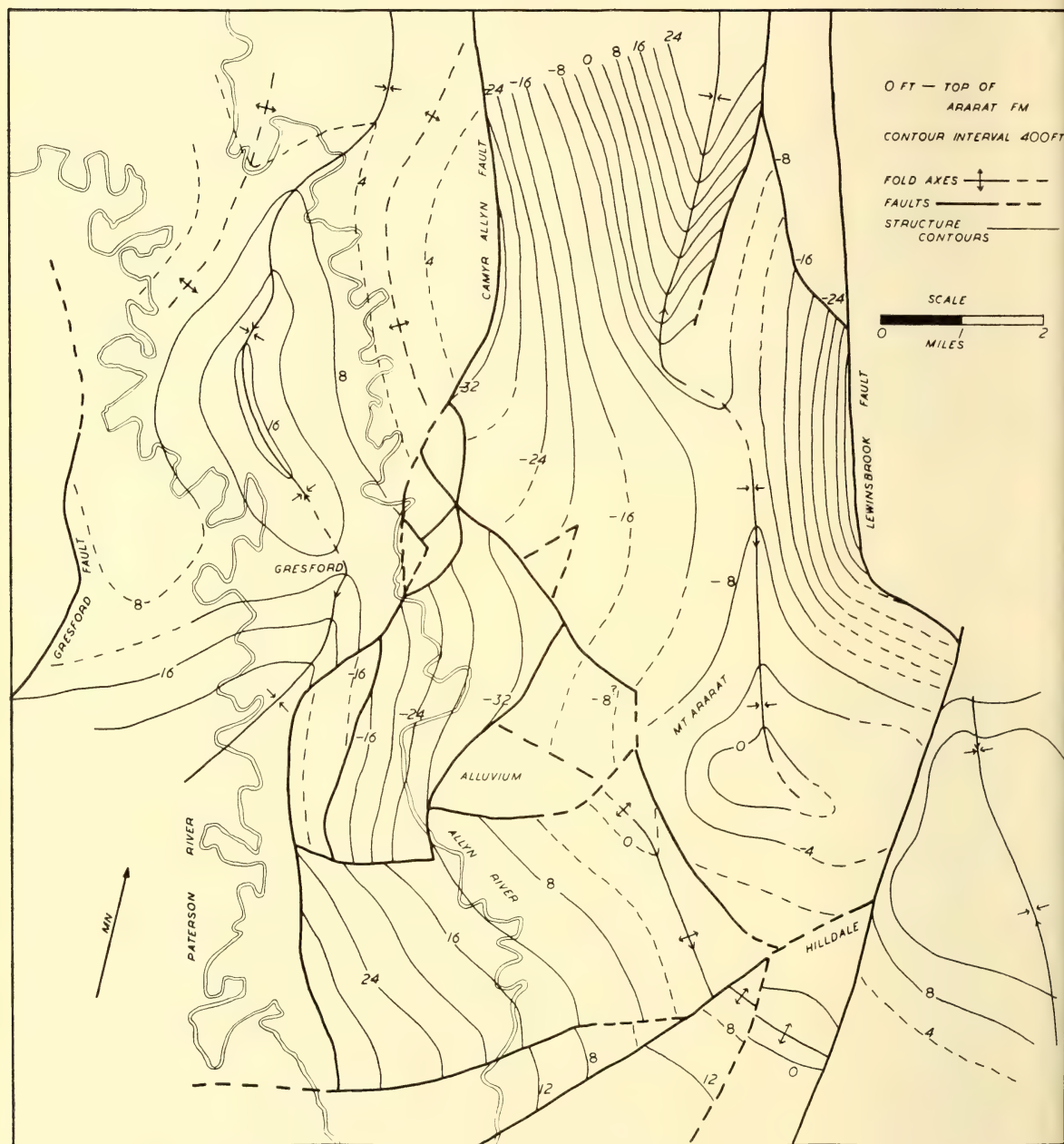


FIG. 4

Structure contour map of the Gresford District contoured on the top of the Ararat Formation

Occultations Observed at Sydney Observatory During 1959-60

K. P. SIMS,

(Received March 17, 1961)

The following observations of occultations were made at Sydney Observatory with the 11½ inch telescope. A tapping key was used to record the times on a chronograph. The reduction elements were computed by the method given in the Occultation Supplement to the *Nautical Almanac* for 1938 and the reduction completed by the method given there. For 1959 the necessary data were taken from the *Nautical Almanac* for 1959, the Moon's right ascension and declination (Hourly table) and parallax (semi-diurnal table) being interpolated therefrom. No correction was applied to the observed times for personal effect but a correction of -0.00228 hour was applied before entering the ephemeris of the Moon. This corresponds to a correction of -4".5 to the Moon's mean longitude. For 1960 a correction

of +0.00944 hour (=34 seconds) was applied to the observed time to convert it to ephemeris time with which *The Astronomical Ephemeris for 1960* was entered to obtain the position and parallax of the Moon. The apparent places of the stars of the 1960 occultations were provided by H.M. Nautical Almanac Office.

Table I gives the observational material. The serial numbers follow on from those of the previous report (Sims 1959). The observers were H. W. Wood (W), W. H. Robertson (R) and K. P. Sims (S). In all cases the phase observed was disappearance at the dark limb. Table II gives the results of the reductions which were carried out in duplicate. The Z.C. numbers given are those of the *Catalog of 3539 Zodiacal Stars for the Equinox 1950.0* (Robertson, 1940).

TABLE I

Serial No.	Z.C. No.	Mag.	Date	U.T.	Observer
384	532	7.2	1959 Jan. 19	12 03 14.7	S
385	1072	6.2	1959 Apr. 15	10 52 59.5	S
386	1428	3.8	1959 Apr. 18	12 14 10.8	W
387	2064	6.5	1959 June 17	8 42 31.1	S
388	2555	7.5	1959 Aug. 14	8 15 50.2	R
389	2495	6.0	1959 Oct. 7	10 34 02.8	S
390	2972	6.7	1959 Oct. 10	14 32 02.8	W
391	2975	7.0	1959 Oct. 10	14 45 10.9	W
392	214	6.4	1960 Jan. 6	11 31 50.6	R
393	—	8.7	1960 Jan. 6	11 32 32.7	R
394	581	6.9	1960 Jan. 9	12 38 52.3	W
395	653	4.8	1960 Feb. 6	9 44 27.3	W
396	871	6.9	1960 Mar. 6	9 04 19.4	W
397	1247	6.8	1960 Mar. 9	10 21 44.5	S
398	764	5.0	1960 Apr. 29	7 47 02.4	S
399	1158	5.2	1960 May 2	8 31 11.6	R
400	1386	6.6	1960 May 4	10 45 33.5	R
401	1486	4.6	1960 May 5	8 23 15.5	W
402	1600	5.1	1960 May 6	10 42 02.6	R
403	1114	6.8	1960 May 29	7 38 46.4	W
404	1746	7.1	1960 July 1	11 52 02.5	S
405	2089	6.8	1960 July 4	7 58 45.9	R
406	2231	6.9	1960 July 5	9 21 49.5	W
407	2495	6.0	1960 Aug. 3	10 43 07.2	S
408	454	5.8	1960 Dec. 28	12 22 51.8	R

TABLE II

Serial No.	Lunation No.	p	q	p ²	pq	q ²	$\Delta\sigma$	$p\Delta\sigma$	$q\Delta\sigma$	Coefficient of	
										$\Delta\alpha$	$\Delta\delta$
384	446	+68	+73	47	+50	53	+0.5	+0.3	+0.4	+7.9	+0.83
385	449	+74	-67	55	-50	45	0.0	0.0	0.0	+9.6	-0.74
386	449	+42	-91	18	-38	82	+1.9	+0.8	-1.7	+2.5	-0.99
387	451	+43	-90	18	-39	82	+1.3	+0.6	-1.2	+2.9	-0.98
388	453	+94	-34	88	-32	12	-1.7	-1.6	+0.6	+13.4	-0.35
389	455	+84	-55	70	-46	30	+1.3	+1.1	-0.7	+11.6	-0.59
390	455	+48	-88	23	-42	77	+2.1	+1.0	-1.8	+9.4	-0.77
391	455	+85	-53	72	-45	28	+1.0	+0.8	-0.5	+13.6	-0.36
392	458	+53	+85	28	+45	72	+0.5	+0.3	+0.4	+3.8	+0.97
393	458	+58	+81	34	+47	66	-2.1	-1.2	-1.7	+4.7	+0.95
394	458	+89	+45	80	+40	20	-1.8	-1.6	-0.8	+11.5	+0.59
395	459	+95	+30	91	+29	9	-1.0	-1.0	-0.3	+12.9	+0.43
396	460	+84	-54	71	-45	29	-1.2	-1.0	+0.6	+12.2	-0.51
397	460	+97	+23	95	+22	5	-1.2	-1.2	-0.3	+14.4	+0.06
398	462	+66	+75	44	+50	56	-0.6	-0.4	-0.4	+8.4	+0.80
399	462	+96	+27	93	+26	7	-1.2	-1.2	-0.3	+14.1	+0.15
400	462	+60	+80	36	+48	64	-1.2	-0.7	-1.0	+11.3	+0.63
401	462	+99	-13	98	-13	2	-0.1	-0.1	0.0	+13.6	-0.39
402	462	+83	+55	70	+46	30	-0.5	-0.4	-0.3	+14.3	+0.28
403	463	+95	+32	90	+30	10	-2.3	-2.2	-0.7	+13.8	+0.22
404	464	+98	-22	95	-22	5	+1.2	+1.2	-0.3	+12.9	-0.51
405	464	+62	+79	38	+49	62	-2.1	-1.3	-1.7	+11.8	+0.60
406	464	+44	-90	19	-40	81	+1.9	+0.8	-1.7	+3.6	-0.97
407	465	+94	-35	88	-33	12	-3.4	-3.2	+1.2	+12.9	-0.42
408	470	+86	-51	74	+44	26	-0.6	-0.5	+0.3	+14.0	-0.29

The star involved in occultation 393 was not in Z.C., it is G.C. 1782. The apparent place was R.A. 1h 26m 21.68s, Dec. +7° 45' 02". Z.C. 2495, involved in occultation number 407, is a double star, A 10465, and the observer noted that it disappeared in two steps.

References

- ROBERTSON, A. J., 1940. *Astronomical Papers of the American Ephemeris*, Vol. x, Part II.
 SIMS, K. P., 1959. *J. Proc. Roy. Soc. N.S.W.*, **93**, 25; *Sydney Observatory Papers*, **35**.

Sydney Observatory
Sydney

Some Theoretical Studies on the Electro-Migration of Inorganic Compounds on Paper

J. MILLER AND W. F. PICKERING

Newcastle University College, Tighe's Hill, N.S.W.

ABSTRACT—The electro-migration of metal ions on filter paper moistened with various concentrations of disodium ethylene diamine tetra-acetate at different pH values has been studied and it was found that the movement of the metal ion could be related to the degree of dissociation of the metal complex formed. The diffusion of acid liberated at the anode by electrolysis was found to contribute greatly to dissociation of the metal complexes. For the system studied, an equation relating the movement of the metal ion with the stability of the complex and the pH and concentration of complexing agent, was derived.

The rate of movement of the metal ions was also found to be influenced by adsorption by the paper and an adsorption mechanism based on the Donnan Membrane Theory has been proposed to explain the observed behaviour of paper.

The major proportion of publications on electro-migration of inorganic compounds on paper describe experiments designed to separate mixtures and a wide variety of reagents have been used as the background or carrier electrolyte. Many of the carrier electrolytes used were complexing agents and it was observed that the movement of a particular cation could be varied by changing the pH of the solution (Lederer and Ward, 1951, 1952; Strain, 1952; Sato, Diamond, Norris and Strain, 1952; Yasunaga and Shimomura, 1953; Sato, Norris and Strain, 1954, 1955; Engelke, Strain and Wood, 1954; Evans and Strain, 1956; MacNevin and Dunton, 1957). Other studies used unreactive carrier electrolytes on which inorganic compounds were spotted in the form of a complexed species (Macek and Pribil, 1955; Miller, Pickering and Ward, 1956; Bruninx, Eeckhout and Gillis, 1956). These studies indicated that the behaviour of the added complexes could not be interpreted completely in terms of the relative stability of the complexes.

Some aspects of the processes involved in the movement of a complexed species on paper under the influence of an electric field have now been examined and the results of these studies are reported in this paper. The complexing agent selected was ethylene diamine tetra-acetic acid since stability data on the metal complexes of this reagent are well known and the reagent reacts to form 1:1 complexes with metal ions. The influence of factors such as electro-osmosis, saturation current, etc., were minimised by adopting the apparatus and procedure recommended by Bruninx *et al.* (1956).

The investigation was divided into three main parts and for clarity in discussion these parts have been recorded as separate sections in this paper.

Experimental Technique

The electro-migration apparatus used resembles that described by Bruninx *et al.* (1956) but was modified by placing a water-cooled copper plate under the lower glass plate used to hold the paper strip. This modification was found desirable to ensure temperature control. In all tests a potential of 90 volts was applied across the electrodes which dipped into two electrolyte reservoirs. The ends of a 6"×4½" sheet of Whatman No. 3 paper were enclosed in cellophane, and contact between the cellophane and the electrolyte reservoirs was made by a 2"×4" strip of Whatman No. 3 paper.

Before being placed in the apparatus the paper was moistened with the selected carrier electrolyte and excess solution was removed by pressing between filter paper. The apparatus was then pre-conditioned by applying the voltage across the electrodes for an hour. Without interrupting the applied field, 0.01 ml portions of deci-normal metal nitrate solutions were placed on the centre line of the paper sheet with the aid of an Agla micro syringe through openings in the upper glass cover of the apparatus.

The electric field was applied for a further 120 minutes and the new position of the metal ions was then located by spraying with suitable spot reagents. The movement and degree of dispersion of the ion was noted in each case.

1. The Effect of Concentration of Complexing Agent and the pH of the Carrier Electrolyte

Electro-migration studies of the movement of seven cations were made using solutions of disodium ethylene diamine tetra-acetate as carrier electrolyte, the concentrations of electrolyte used being respectively 0.25, 0.10 and 0.01 molar in the separate series of tests. The pH of the solutions was adjusted to either 4.4, 8.2 or 10.7 by the addition of sodium hydroxide and an ionic strength of 1 was maintained by the addition of potassium nitrate.

The movement of the metal ions (in mm) and the degree of diffusion of the spots (reported in parentheses as a multiple of the original spot size) under the different conditions, are recorded in Table I. Movement towards the cathode has been recorded as positive movement (e.g. +15 mm) and movement towards the anode (i.e. due to movement of an anion) has been recorded as negative. The distance moved by a metal ion was measured from the starting line to the centre of the resultant spot. In those cases where the recorded movement is small (i.e. $< \pm 10$ mm) and is accompanied by a large spot area (i.e. > 3) the metal ion was found on both sides of the starting line, indicating that the metal ion was present as both an anionic and a cationic species. These systems have been marked by an asterisk in Table I.

Discussion

An examination of the results recorded in Table I indicates a number of general trends.

- The introduction of E.D.T.A. into the carrier electrolyte reduced the rate of movement of metal ions towards the cathode. This is in accordance with the tendency of the metal ions to form anionic complexes.
- The introduction of KNO_3 into the carrier electrolytes containing E.D.T.A. had little influence on the rate of movement where the concentration of E.D.T.A. present was equal to or greater than the concentration of metal nitrate spotted on the paper. However, where the complexing agent was present in low concentration (e.g. 0.01M) the introduction of the KNO_3 resulted in a complete change of direction for the divalent metal ions. This reversal of direction has been found to be due to the increased current which flows in the circuit with a concomitant interference introduced through diffusion of electrolysis products. This

TABLE I
Electro-migration of Metal Ions

Spotted Solute	Carrier Electrolyte Solution									
	E.D.T.A. Solutions containing KNO_3 (Ionic Strength 1)									
	0.010N Metal Nitrate	0.25M E.D.T.A.	0.10M E.D.T.A.	0.01M E.D.T.A.	0.25M	0.10M	0.01M	0.25M	0.10M	0.01M
Ag^+	+33(12)	+12(4)	+33(6)	+12(8)	+23(3)	+19(6)	+30(10)	-33(2)	-35(5)	+25(9)
Cu^{++}	+62(3)	+25(2)	-33(3)	-15(3)	-25(2)	-30(2)	+5(6)*	-24(2)	-29(2)	+8(7)*
Cd^{++}	+47(3)	-23(1)	-27(3)	-16(3)	-21(1)	-27(2)	+7(7)*	-21(1)	-24(1)	+18(5)
Co^{++}	+63(3)	-20(1)	-28(3)	-11(3)	-26(1)	-22(2)	+25(10)	-25(1)	-27(1)	+36(7)
Ni^{++}	+61(3)	-25(1)	-28(3)	-15(3)	-26(1)	-25(2)	+8(9)*	-26(1)	-28(1)	+8(7)*
Zn^{++}	+65(3)	-19(1)	-28(3)	-15(3)	-22(1)	-28(2)	+15(5)	-19(1)	-30(2)	+16(7)
Fe^{++}	+55(3)	-12(1)	-20(3)	-9(3)	-14(1)	-11(2)	-6(7)*	-13(1)	-18(2)	-
pH of Carrier Electrolyte	4.4									
	8.2									
	10.7									

NOTES: Applied Field, 4 V/cm; Time 2 hrs.; Whatman No. 3 Paper; Movement towards cathode recorded as positive.

aspect is discussed in more detail in Section 2 of this paper.

(c) Varying the concentration of E.D.T.A. in the carrier electrolyte produced some unexpected effects. It was predicted that the movement of the metal ion would become more negative as the concentration of complexing agent was increased (due to reduced dissociation of the anionic complex ions) and this was certainly the case when the concentration was increased from 0.01 to 0.1M E.D.T.A. However, a further increase in E.D.T.A. concentration to 0.25M resulted in a slightly lower rate of movement from that obtained with 0.1M carrier electrolyte, but the resultant spots were more compact. This slight retardation has been attributed to an adsorption phenomena and this aspect is more fully discussed in Section 3 of this paper.

(d) Increasing the pH of the carrier electrolyte was predicted to favour the formation of the anionic complex species and thus increase the rate of negative movement of the metal ions. However, it was observed (cf. Table I) that with the exception of silver (which changes direction between pH 4.4 and 8.2), changing the pH had little significant influence on the movement of the ions. The variation in movement obtained at pH 10.7 using 0.01M E.D.T.A. as carrier electrolyte when compared with the values obtained with the same carrier at lower pH values is most readily explained in terms of neutralisation of electrolysis products as will be discussed later. The limited influence of pH on the movement can be attributed to the stability of the metal-E.D.T.A. complexes.

It was shown by Consden, Gordon and Martin (1946) that the degree of separation of weak electrolytes and amphoteric substances depends upon the degree of dissociation. By analogy with the treatment used by these workers for weak acids, the effective mobility of a complexed metal ion can be considered to be controlled by the relative proportions of complex species and hydrated metal ion (due to dissociation) present under the conditions of electro-migration and the following equation has been derived for a 1 : 1 molar complex.

$$d = \frac{F \cdot t (K_c \cdot K_a \cdot C_a \cdot U_{pc} + C_h U_{pm})}{C_h + K_a C_a K_c} \quad \dots (1.1)$$

where d is distance moved by metal ion in time t under influence of electrical field F , and

K_c = Stability constant of metal-ligand complex

K_a = Dissociation constant of ligand acid

C_a = Concentration of ligand acid in the carrier electrolyte

C_h = Concentration of hydrogen ions in the carrier electrolyte

U_{pc} = Mobility of complex species on paper. (—ve in sign)

U_{pm} = Mobility of metal cation on paper. (+ve in sign)

The mobility (U) on paper can be measured in terms of a unit such as cm/volt cm⁻¹/sec where the distance travelled by the species (in cm) is measured along the surface of the paper from the starting point and includes any retarding effects due to electro-osmosis etc. and where the field strength (volt cm⁻¹) is obtained by dividing the applied voltage by the length of the paper strip.

If complex formation involves the displacement of more than one proton from the ligand acid, then C_h must be raised to the power of the number of protons displaced. Thus, for the E.D.T.A. complexes studied (within the pH range of 4 to 11) C_h in equation (1.1) should be replaced by $(C_h)^2$.

The mobilities U_{pc} , U_{pm} can be considered to be of the same order of magnitude even though they may differ in sign, and accordingly, a study of equation (1.1) indicates that the C_h term will only be significant when it is approximately equal to or greater than the term $K_a \cdot K_c \cdot C_a$.

For the E.D.T.A. system studied, C_a ranged from 0.25 to 0.01 molar and K_a (for the equilibrium $H_2Y \rightleftharpoons 2H^+ + Y^{4-}$) is equal to $10^{-16.4}$. A change in hydrogen ion concentration in the solution could thus be expected to cause significant variations only when $(C_h)^2 \gtrsim 10^{-17} \cdot K_c$. With the series of complexes studied and considering only pH values ranging from 4 to 11, only silver E.D.T.A. complex has a K_c value ($10^{7.3}$) which satisfies this relationship and it can be observed from Table I that the direction of movement of silver was reversed when the pH was varied from 4.4 to 8.2. Substitution of appropriate values in equation (1.1) (U_{pm} being taken from the movement in M.KNO₃ solution and assumed equal to $-U_{pc}$) yielded values for the movement of silver ion under different conditions which compared well with the values obtained by experiment.

With more stable complexes (e.g. those of the divalent metals, $K_c \sim 10^{18}$) it can be shown

that the direction of movement of the metal ion should change from negative to positive at much lower values of pH (e.g. $<1-2$) but calculation of the exact conditions is complicated by the limited solubility of the quadribasic acid (H_4Y) which will be present under these conditions.

Because of the marked stability of the iron E.D.T.A. complex ($K_c=10^{25}$) conditions never became sufficiently acidic on the paper to cause dissociation of the complex and thus no cationic movement was observed in the presence of E.D.T.A.

migration of hydrogen ions produced at the anode.

Universal indicator was mixed with a range of the carrier electrolytes used in these two studies and changes in pH on the paper were visually observed. The indicator showed that an acid front slowly spread from the anolyte reservoir and an indication of the rate of movement of the acid front using different electrolytes is given in Figure 1. The pH of the electrolytes in the anode and cathode reservoirs was determined at time intervals and the results obtained are summarised in Figure 2. Measurements

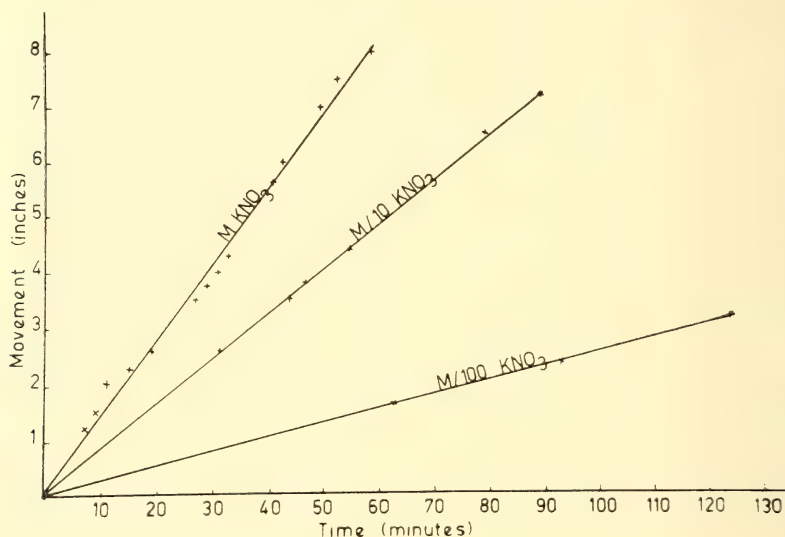


FIG. 1

Graph showing the variation in the rate of movement of the acid front across the paper strip with concentration of carrier electrolyte. Field Strength 4 V/cm

Using a complexing agent as carrier electrolyte, the movement of an added metal ion can therefore be related to the degree of dissociation of the complex which in turn is related to the concentration of complexing agent present and the pH conditions prevailing.

2. The Diffusion of Electrolysis Products

A previous study (Miller, Pickering and Ward, 1956) using potassium nitrate solutions as carrier electrolytes indicated that stable metal complexes were decomposing during electromigration on paper. In this latest study, great difficulty was found in obtaining reproducible results using solutions containing predominantly potassium nitrate (e.g. 0.01M E.D.T.A. in $M.KNO_3$). In both cases, the metal ions exhibited cationic movement and the reason for this was traced in the following manner to

were also made of the movement of silver and nickel ions when molar solutions of the nitrates of these metals were used as the anolyte and a molar solution of potassium nitrate was used to moisten the paper and act as the catholyte. The rate of movement of the silver and nickel ions across the paper is shown in Figure 3.

Discussion

The rapid change in pH which can occur in the electrolyte reservoirs in the absence of a buffer salt is clearly shown in Figure 2. The amount of acid or base formed at the electrodes is controlled by Faraday's Laws and thus the rate and extent of the pH changes varies with the time and the current flowing in the circuit. For a given applied voltage, the current in turn is controlled by the concentration and nature of the carrier electrolyte and the wetness of the paper.

The hydrogen ions formed in the anode compartment were free to move under the influence of the applied electrical field and it can be observed from Figure 1 that an acid front moved across the paper at a rate which varied linearly with time. The rate of movement of the acid front also varied with the concentration of carrier electrolyte used and from Figure 2 this can be related to the rate at which hydrogen ions were being formed in the anolyte reservoir.

which permits the calculation of a "tortuosity factor" (Lederer, 1955). The calculations are only valid in the absence of adsorption of a species, and the limitations inherent in the application of "tortuosity" or "obstructive" factors have been emphasised in a recent paper by Bailey and Yaffe (1959).

Calculations based on the information shown in Figure 3 gave values for the "factor" of 0.7 (Ni^{2+}), 0.6 (H^+) and 0.5 (Ag^+). The value calculated using the nickel results is similar to

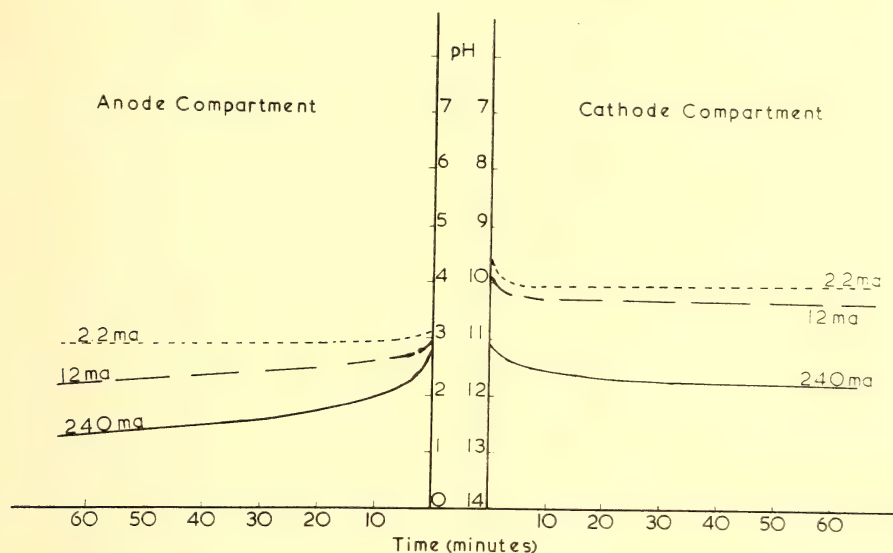


FIG. 2

Graphs showing the rate of change of pH in the electrolyte reservoirs. The recorded currents (in the order of increasing magnitude) correspond to the use of centi-, deci- or molar solutions of potassium nitrate as carrier electrolyte

The effect of concentration of acid in the anolyte reservoir on the rate of movement of the acid front over the paper is inexplicable in terms of the mobility of free ions in solution, and this phenomenon is most readily explained in terms of adsorption of hydrogen ions by the paper. A similar explanation was required in a paper chromatographic study (Pickering, 1958) where it was observed that the height ascended by an acid front varied almost linearly with the concentration of acid in the developing agent. The adsorption of ions by the paper is also indicated by the results recorded in Figure 3, and the large spot areas recorded in many places in Table I.

The apparent difference in the rate of movement of a species in solution and on paper has been attributed to the species following a tortuous path in between the fibres of the paper and an empirical equation has been derived

values quoted for other grades of paper (Lederer, 1955), hence the lower values calculated from the movement of hydrogen and silver ions can be attributed to adsorption of these ions by the paper.

Since some of the electro-migration results recorded in Table I indicated adsorption of complex anions as well as cations, the adsorptive properties of filter paper are discussed in the next section of this paper.

Studies with neutral sugar molecules confirmed the claims of Bruninx *et al.* (1956) that the design of apparatus used in this study minimises, and virtually eliminates, solvent flow along the paper. However, the diffusion of electrolysis products along the paper during the recommended pre-conditioning period may completely alter the pH and composition of the carrier electrolyte before the metal ions are placed on the paper. For example in the series

of experiments recorded in Table I variable results were obtained with carrier electrolytes composed of molar potassium nitrate containing centi-molar E.D.T.A. The diffusion tests showed that these carrier electrolytes became quite acidic during the pre-conditioning period (even those solutions which were originally adjusted to a pH of 10) and thus the metal ions were actually being spotted on to an acidic

several ways. Some success may be obtained by incorporating mechanical baffles in the reservoir compartments but the preferable techniques are those based on the use of a buffer solution (of sufficient strength to absorb all products formed), a weak electrolyte or a strong acid as carrier electrolyte. Most of the published electro-migration studies have used such solutions and hence the possible influence

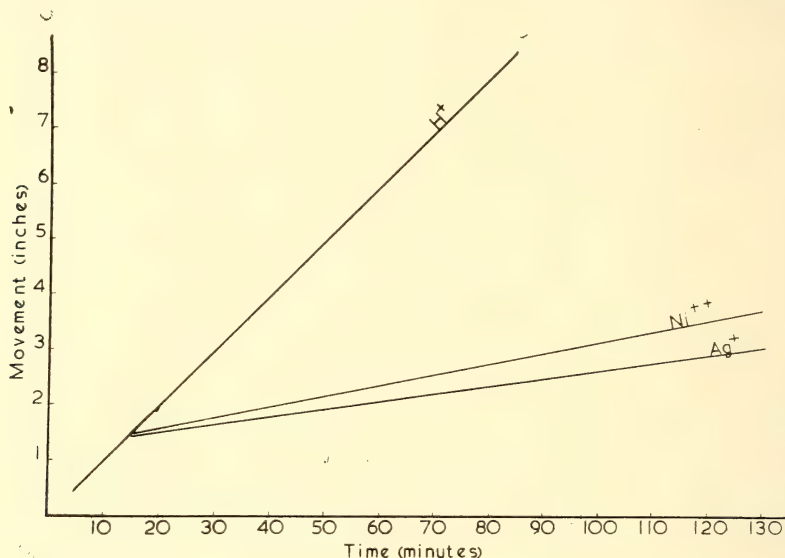


FIG. 3

Graph showing the rate of movement of hydrogen, nickel and silver ions along the paper. Carrier electrolyte M.KNO₃, field strength 4 V/cm. (Graphs for Ag⁺ and Ni²⁺ have been displaced upward for clarity)

solution of potassium nitrate (most of the E.D.T.A. being precipitated as the sparingly soluble acid) rather than on to an alkaline solution of complexing agent. It is therefore not surprising that the divalent metals exhibited cationic movement with these electrolytes in comparison with the anionic movement observed when 0.01M E.D.T.A. (without added KNO₃) was used as carrier electrolyte.

The rate of movement of the alkali front from the cathode compartment was very much slower than that of the acid front. In the time intervals used in this investigation, on no occasion did the alkali front extend any distance past the end of the paper bridge from the cathode reservoir. This can be partially explained by the difference in mobility between hydrogen and hydroxyl ions and partially due to smaller concentration of hydroxyl ions formed during electrolysis (cf. Fig. 2).

The undesirable effects introduced by diffusion of electrolysis products can be overcome in

of electrolysis products has not received much attention even though a number of workers have observed that a particular species may change direction during the period of electro-migration. However, this study emphasises that acid diffusion must be seriously considered on any occasion when the use of the chosen carrier electrolyte will result in the flow of more than a few milliamperes of current and where acidic conditions are not desired.

3. The Adsorption of Complexed Species by Filter Paper

Recent chromatographic studies (Pluchet and Lederer, 1960; Beckmann and Lederer, 1960) have demonstrated that anions may be adsorbed by filter paper. In the case of the chloro-complexes of a number of metals it was shown that the movement of the metal ion varied with the concentration of HCl in the developing solvent, there being optimum movement within ranges of acid concentration which varied with

the metal ion. A similar observation was made by Pucar (1957, 1958) during a study of electrophoresis on paper involving the halogen complexes of a number of metals. The results recorded in Table I indicate that movement of the metal-E.D.T.A. complexes reaches a maximum within an intermediate range of concentration of complexing agent (approximately 0.1M).

Further evidence of the adsorption of complex ions was found when spots of deci-normal solutions of a series of metal complexes were developed on paper chromatograms with deci-normal solutions of either nitric acid, potassium nitrate or sodium hydroxide. With the latter two developing agents, adsorption was clearly indicated by extensive tailing along the path of the chromatogram. The magnitude of the effect is shown diagrammatically in Figure 4 by means of the size of the symbols used and unclosed symbols which represent tailing back to the original point of application.

The relative movement of the metal ions for all the complexes tested using deci-normal acid as developing agent has not been recorded on Figure 4, since in all cases the movements were similar to the movement of the hydrated metal ion and corresponded to the position of the acid front on the chromatogram. Thus, the presence of a reasonable concentration of acid in an aqueous developing agent can cause displacement and/or destruction of a complex ion. The same effect was observed during the migration of an acid front across the paper support in the electro-migration studies.

The adsorption of hydrogen ions and other cations by filter paper has been shown to be due to cation exchange and the cation exchange capacity of untreated filter papers has been found to vary from 3 to 50 microgram equivalents per gram of paper (Schonfeld and Brode, 1951; Ultee and Hartel, 1955; Pickering, 1960).

This small exchange capacity can be used to explain the adsorption of cations by paper from dilute solutions but explanation of other adsorption effects such as the retention of anions, the effect on concentration of complexing agent, etc., requires a more general concept. The mechanism of ion exchange by resins of much greater capacity has been explained in terms of the Donnan Membrane Theory and a model based on this theory appears to explain most of the observed adsorption characteristics of filter paper.

Proposed Mechanism of Adsorption by Filter Paper

The functional groups present on paper can be regarded as non-diffusible ions present in a water swollen paper phase, separated from an external aqueous solution by a cellulose-water interface. This interface can be considered to act as a membrane and by the Donnan theory an electrolyte (e.g. A_yB_x) from the external solution will pass through the membrane until the relationship

$$(a_{Ax+})_p^y \cdot (a_{By-})_p^x = (a_{Ax+})_w^y \cdot (a_{By-})_w^x \quad \dots (3.1)$$

is satisfied. (Subscripts "p" and "w" indicate the paper and water phases respectively.) If the aqueous phase contains a number of electrolytes, each electrolyte will satisfy the same general relationship.

For the purpose of discussion, this expression may be simplified by considering only monovalent ions and by assuming that the activity coefficients of the ions are the same in both phases. The simplified equation may be written:

$$[A^+]_p \cdot [B^-]_p = [A^+]_w \cdot [B^-]_w \quad \dots (3.2)$$

Because the paper phase also contains non-diffusible anions, R^- , the principle of electrical neutrality requires that $[A^+]_p = [R^-]_p + [B^-]_p$ from which it can be seen that $[A^+]_p > [B^-]_p$. Accordingly, if equation (3) is to be satisfied, $[B^-]_p < [B^-]_w$. In other words, the concentration of diffusible anions in the paper phase (as indicated by $[B^-]_p$) will be lower than the concentration of the same anion in the water phase, the difference in magnitude being related to the concentration of non-diffusible anion in the paper phase.

For resin ion exchangers it has been shown by Samuelson (1953) that the volume of the resin phase can be considered as the volume of the swollen resin. With an exchange capacity of several milli-equivalents per gram, this corresponds to a concentration of non-diffusible anion in the resin phase of the order of 5-6N, and since this is far greater than the concentration of ions normally present in the aqueous phase, the concentration of diffusible anion in the resin phase is small enough to be ignored.

By analogy, if the volume of swollen paper fibres is taken to represent the volume of the paper phase, the small concentration of negatively charged functional groups attached to the paper corresponds to a concentration of non-diffusible ions (i.e. $[R^-]_p$) of the order of $10^{-2}N$. In this case, the concentration of anions present in the paper phase due to diffusion

Relative Movement	COMPLEXING AGENT PRESENT							CATION
	WATER	AMMONIA	ETHYLENE DIAMINE.	PYRIDINE	CYANIDE	E. D. T. A.	SULPHO - SALICYLIC ACID	
0.8 0.6 0.4 0.2								<u>COPPER</u>
0.8 0.6 0.4 0.2								<u>NICKEL</u>
0.8 0.6 0.4 0.2								<u>COBALT</u>
0.8 0.6 0.4 0.2								<u>ZINC</u>
0.8 0.6 0.4 0.2								<u>CADMIUM</u>

FIG. 4

The Movement of Complexed Metal Ions on Filter Paper using Aqueous Solvents, such as deci-molar KNO_3 or NaOH . The symbols \bullet \bullet indicate the relative positions of the cations after development. A triangular peak (\blacktriangle or \blacktriangledown) represents values obtained in alkaline solution which differed from values obtained with KNO_3 solution. Tailing from the original spot is indicated by an open symbol and the area of the symbol indicates the comparative degree of diffusion of the ion over the paper

through the membrane may often be greater than the concentration of functional groups. For example, if $[A^+]_w = [B^-]_w = 0.100N$, and $[R^-]_p = 0.010N$, then by equation (3) $[B^-]_p = 0.095N = 9.5[R^-]_p$.

It is in this respect that the adsorptive properties of the filter paper differ greatly from those of artificially made resin exchangers. However, if the concentration of functional groups on the paper is increased by any process (e.g. oxidation, phosphorylation, etc.), then the behaviour of the paper will tend to more closely resemble the pattern of conventional resin exchangers.

The possibility of such high concentrations of diffusible anion (B^-) in the paper phase explains the observed adsorption of anions. The above example also demonstrates that only a small percentage of cations present in the paper phase to maintain electrical neutrality need be attached to functional groups. Therefore, conversion of the functional groups to the less reactive hydrogen form will not necessarily eliminate adsorption of metal ions by the paper.

This model also explains why there is an optimum concentration of complexing agent in the carrier electrolyte which ensures maximum rate of movement of the complexed species. When the concentration of complexing anion (e.g. halide or E.D.T.A.) in the aqueous phase is of the same order as the concentration of functional groups in the paper phase, few complexing anions will be present in the paper phase. If a metal ion is now introduced into the system, there will be competition for this ion between the functional groups and complexing anion. If the metal forms a stable complex, the anionic species formed in the water phase will move under the influence of the electrical field with little retardation due to distribution into the paper phase. If the complex is unstable, some metal ions will be retained in the paper phase by attachment to the fixed functional groups. At the other extreme, if the concentration of complexing anions in the aqueous phase is much greater than the concentration of functional groups (i.e. $[B^-] \gg [R^-]$), there will be a corresponding high concentration of ligand groups in the paper phase. An added metal ion may then form a stable complex in both phases. Movement of the metal complex formed within the paper phase will only occur after the concentration of complex in the water phase has been reduced by migration. The complex in the paper phase may then diffuse out into the water phase to maintain equilibrium and migrate

under the influence of the electrical field. This distribution between the two phases will retard the rate of movement of the species. The optimum conditions will thus be those which provide sufficient excess ligand to ensure a minimum of dissociation of the complex with a minimum of excess ligand being distributed into the paper phase.

There is evidence that filter paper can be selective in regards to the size of the ion adsorbed (Fouarge and Duyckaerts, 1960) and thus the movement of a complex species can be influenced by size in two ways, (i) through its effect on the mobility of the ion, and (ii) through adsorption effects.

Another factor which must be considered is the high degree of swelling of paper in the presence of electrolyte solutions. The degree of swelling will vary with the composition of the aqueous phase and this swelling in turn will control the volume of the paper phase and the selectivity of the membrane in regard to size.

For this and other reasons (such as difficulty in assigning values to activity coefficients in the paper phase) the proposed adsorption mechanism (as summarised by equation (2)) is of great value in qualitative explanation of the behaviour of ions on paper but the explanations cannot be made quantitative. From equation (2) it can be seen that adsorption will be favoured by any process within the paper phase which reduces the activity of the species being considered. Reduction in activity may result from attraction to functional groups; bonding to hydroxyl or other groupings in the cellulose molecule; or inter-ionic attractions. In this way, the theory includes mechanisms which have been proposed by other workers. For example, Hanes and Isherwood (1949) proposed that solutes and solvents compete for positions in a water-cellulose complex; Burma (1953) suggested that solutes were distributed between a "free" water phase and a "fixed, non-solvent" water phase; Pluchet and Lederer (1960) proposed that the adsorption of anions was analogous to a salting out or precipitation process; and Beckmann and Lederer (1960) explained the retardation of chloro-complexes in terms of "solution" in the paper.

Reference to equation (2) also indicates that adsorption of a species on paper will be reduced by any process or reaction in the aqueous phase which reduces the activity of the species in this phase. For a given zone of paper, the activity of a particular ion in the aqueous phase above this zone may be reduced by such processes as complex formation, ion-association, electrical

migration or distribution into an organic solvent.

The proposed mechanism is therefore sufficiently general to include mechanisms proposed by previous workers and can be used to interpret the behaviour of ions on paper which is being used as a support in either electro-migration or partition chromatography studies.

Conclusions

In electro-migration on paper using complexing agents as carrier electrolytes, the movement of an added metal ion can be related to the degree of dissociation of the metal complex formed. The extent of dissociation varies with the concentration of ligand present and the pH conditions prevailing in the solution. Variations in pH can occur due to diffusion of hydrogen ions formed at the anode of electrolysis.

The rate of movement of a species on paper can also be related to the adsorptive properties of filter paper. The adsorption process can be considered in terms of a model based on the Donnan Membrane Theory and this approach can be used to explain observed adsorption phenomena in electro-migration and partition chromatography studies based on a paper support.

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The Sequence of Tertiary Volcanic and Sedimentary Rocks of the Mount Warning Volcanic Shield

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ABSTRACT—In this paper the writer presents the sequence of volcanic and sedimentary rocks in the Mount Warning volcanic shield and also attempts to analyse some aspects of their origin and depositional environment.

The shield is composed of basalts which issued from a vent now represented by the Mount Warning central complex. Interbedded in the basalts on the flanks of the shield are a number of local rhyolite flows and associated pyroclastics which were delivered from subsidiary vents, the plugs of which are still evident. Also interbedded are lacustrine sediments which were derived principally from basement country rocks and which give some indication of the age of the shield and of subsequent earth movements.

The oldest Tertiary rocks in the area appear to be the volcanic domes around Woodenbong and Mount Barney. However, an argillaceous sedimentary sequence actually forms the basal member of the pile. Then follows 800 feet of basalt which is overlain by an excellent 200-foot marker band of agglomerates, tuffs, brecciated rhyolite and an associated polymictic conglomerate.

Above this, there is over 2,800 feet of basalt which contains thick intercalations of rhyolite and acid tuff in four distinct localities, namely the Binna Burra, Mount Lindesay and Canungra areas and the Nightcap Range. These all appear to be on the same stratigraphic horizon.

Introduction

Previous work on the Mount Warning Shield has been incomplete mainly due to the influence of the interstate boundary, whereby a quarter of the shield area lies in Queensland and the remainder in New South Wales. Richards (1916), working on the Queensland section, recognized the presence of the rhyolite bands but he erroneously correlated the two acid levels and demarcated Lower (basic), Middle (acid) and Upper (basic) Divisions of volcanic rocks. He also included the acid and alkaline plugs to the west in his Middle Division. This concept has prevailed for almost half a century and was accepted by Tweedale (1951), who worked in the Binna Burra area in Queensland, in part by Crook and McGarity (1956), who carried out surveys in the Minyon Falls area, N.S.W., and by McElroy (1959), who has just completed a survey of the New South Wales section of the Clarence-Moreton Basin.

Bryan (1959), using chemical analyses, correlated the Lower Division of Richards with the Silkstone Formation at Ipswich in Queensland. Recently, Solomon (1959) has elucidated the geology of the central complex of Mount Warning and also has made observations on the geomorphology of the shield and the erosion caldera.

The 1800-square-mile shield embraces the McPherson Range (which constitutes the New South Wales-Queensland border), the Tweed Range and its southerly extension, the Nightcap Range. On the dissected northerly fall of the McPherson Range are the Springbrook and Lamington Plateaux, much of which are set aside as national parks. Both parks are readily accessible by trafficable roads to

Christmas Creek, the Lost World, O'Reilly's, the Darlington Range, Binna Burra, the Numinbah Valley and Springbrook and there is also an excellent network of tracks through both reserves.

The Tweed Range is included for the most part in the Wiangaree and Mebbin State Forests and the Nightcap Range in the Whian-Whian State Forest. The southern part of the shield gives way to the gently undulating northern slopes of the Richmond Valley, the lateritized basalt soils of which support an intense dairying industry.

The greater part of the shield above the Hillview Rhyolite level is thickly covered with wet sclerophyll and rain forests. In the Tweed Range and the western part of the Lamington Plateau access is extremely difficult and visibility severely restricted in heavy rainforest. Any investigator of these areas needs to be an expert bushman or a member of a party.

This survey, from the very nature of the terrain of the area, is necessarily on a regional scale. Much of the area of the McPherson and Tweed Ranges and the Lamington Plateau was mapped during excursions with members of the University of Queensland Bushwalking Club. Within the erosion caldera seven traverses were made up the escarpment. The outer portions of the shield remnants were examined by road traverses, principally, some short foot traverses being made into unserved areas.

Geomorphology

The present disposition of the lavas depicts a rough concentricity about Mount Warning with a 120-degree sector denuded from the

coastal side and a core of seven miles radius partly removed to form a central erosion caldera. The average radius of the outcrop area is about 30 miles, but outliers of basalt over 40 miles from the central plug indicate that the shield originally was of much larger areal extent. The maximum thickness of the pile at any one point is 3,400 feet at Mount Hobwee (3,960 feet) on the caldera rim. On the opposite side of the caldera in the Nightcap Range the thickness is only 2,600 feet, while at Mount Lindesay, a distance of 33 miles from Mount Warning, the thickness is also 2,600 feet. These figures indicate that the shield lavas flowed a considerable distance in a westerly direction at least; this will be discussed further later in this paper.

The most conspicuous physiographic feature of the area is the erosion caldera in which the three arms of the Tweed River have carved out a gigantic amphitheatre, some fourteen miles diameter, almost perfectly symmetrically disposed about the 3,793 feet spire of Mount Warning. Most of the floor of the caldera is below the 400 feet contour, so that the masses of the McPherson, Tweed and Nightcap Ranges, rising in an almost continuous precipitous wall to heights of three and four thousand feet, form an impressive scene. Observations on this unusual topographic pattern prompted Professor Dorothy Hill (1951) to suggest first that it was an erosion caldera and that Mount Warning might be the focus of a volcanic shield. A description of the caldera and the possible mechanisms of its formation have been adequately discussed by Solomon (1959).

Peripherally from the caldera rim, erosion trends are radial, resulting in a digital pattern of spurs and canyons that persists to the outer edge of the shield remnant. The only major exception to this is the upper part of the Richmond River where there is a superimposed north-south drainage pattern due to late Tertiary differential uplift in the Richmond Range area.

Basement and Tectonic Environment

The Mount Warning central stock lies exactly on the boundary between Lower Palaeozoic sediments to the east and Mesozoic basal volcanics to the west. That there is at least a steep unconformity surface between the two is shown by steeply dipping Mesozoic strata around Chillingham. However, there is little evidence for a faulted junction as might be suggested from such a position of the plug, though this may well be the case and such a

line of possibility would certainly warrant investigation by any future worker on the Mesozoic rocks in this area.

Much of the eastern Palaeozoic massif formed a basement high for the Tertiary lavas, up to 1,000 feet above the general level of the Mesozoic basement. Section A-B shows that no lavas covered some Palaeozoic areas till the second basalt episode.

To the west, the dominant basement structures are the Beaudesert Syncline (Reid, 1922; Morton, 1923), and the Overflow Anticline, the latter being persistent from Flinder's Peak in Queensland to west of Casino, at least, in New South Wales. These structures are secondary folds of the main Clarence-Moreton Basin (McElroy, 1959) (=Moreton Offshoot Basin, Whitehouse, 1955). Their pre-Tertiary existence is shown by Section A-B wherein there is demonstrated the considerable unconformity between the Mesozoic and Tertiary strata.

The Overflow Anticline formed a slight basement high due to its core of more resistant Marburg Formation sandstone, inliers of which occur in the basalt around Grevillia in the Upper Richmond area. On the other hand, the Beaudesert Syncline was an area of lower relief and it is over this structure that the greatest thickness of the lowest basalt was deposited. Other local highs, now often exposed as inliers, existed in the area, e.g. near the head of the Albert River, the area to the north of Nimbin and at Bexhill, near Lismore.

The Tertiary Deposits : (i) Trachytes and the Mount Barney Complex

Around Woodenbong there are a number of trachyte domes with limited associated flows. Of these, Glassy and Dome Mountains offer the only evidence of age relationship. Trachytic lava and tuff from the former extends to the north and north-east over Jurassic Walloon Coal Measures and at several points along the Richmond River above Grevillea similar lava underlies the lowest basalt. In some occurrences there is a conglomerate associated with the lava indicating lacustrine deposition. The shield basalts of the Richmond Range appear to have flowed around Dome Mountain though the exact relationship is obscured by a profuse growth of rain forest.

The Mount Barney intrusive complex (Stephenson, 1959) is most probably of the same age. It is pre-Chinghee Conglomerate (see later) in age, since that stratum contains an abundance of boulders of granophyre, obviously

derived from the Mount Barney central stock, the only local occurrence of that rock type.

In Cainbale Creek, nine miles south-east of Beaudesert, a small laccolithic mass of trachyte underlies the lowest basalt and intrudes Jurassic Walloon Coal Measures. Due to soil development no actual contacts with the basalt can be observed to ascertain its relationship to the Lamington sequence. However, there appears to be no disturbance of the basalt, indicating a pre-shield age for the intrusion.

The Tertiary Deposits : (ii) The Lamington Group

The Lamington Group embraces the sequence of interbedded lavas, pyroclastics and sediments which is excellently exposed in the Lamington Plateau. The total thickness of the group is 3,400 feet at Mount Hobwee on the eastern edge of the plateau. The name replaces Lamington Volcanics (Stephenson, Stevens and Tweedale, 1960).

THE NUMINBAH VALLEY FORMATION

This name is introduced for a sequence of brown and white shales and mudstones that occurs beneath the lowest basalt along the eastern slopes of Turtle Rock in the Numinbah Valley. The beds are up to 100 feet thick and contain abundant dicotyledonous leaf impressions.

Beds of similar lithology and floral content occur in a small outcrop beneath the lowest basalt to the south-east of the Cainbale trachyte. This outcrop was discovered in 1959 by N. H. Simmonds of the Queensland Geological Survey. Apparently equivalent leaf-bearing strata have been noted by the writer below the basalts on the McPherson Range, ten miles west of Coolangatta.

Three miles south-west of Beaudesert near the Mount Lindesay Highway an oil bore encountered shales which contained the fresh-water gastropod *Melania* sp. (Ball, 1924). The area is covered by 100 feet of alluvium but the nearest rock outcrop is the lowest basalt of the Lamington sequence. The shales are therefore considered to be equivalents of the beds described above.

THE ALBERT BASALT

This name is proposed for the lowest basalt of the volcanic pile since its maximum thickness of 800 feet is attained and its full sequence exposed along the valley of the Albert River. The relationship with both the underlying

Numinbah Valley Formation and the overlying Hillview Rhyolite can be seen in Cainbale Creek, a tributary of the Albert River.

The formation is a readily defined unit as far south as Wiangaree in New South Wales, where in the southern part of the Wiangaree State Forest both the Hillview Rhyolite and the associated Chinghee Conglomerate lens out. Eastward it becomes very thin, below the Hillview Rhyolite in the Beechmont Range and it does not extend over most of the Palaeozoic basement high that runs beneath the Springbrook Plateau. Similarly, to the south, in the Tweed Range the sequence thins to 300 feet in the Mebbin State Forest. It probably extends to the Lismore area (whereby it could be the lower part of McElroy's, 1959, Lismore Basalt), though the writer believes that this area may have been a "high" during early shield times and may not have been covered by the Albert Basalt sequence (see later).

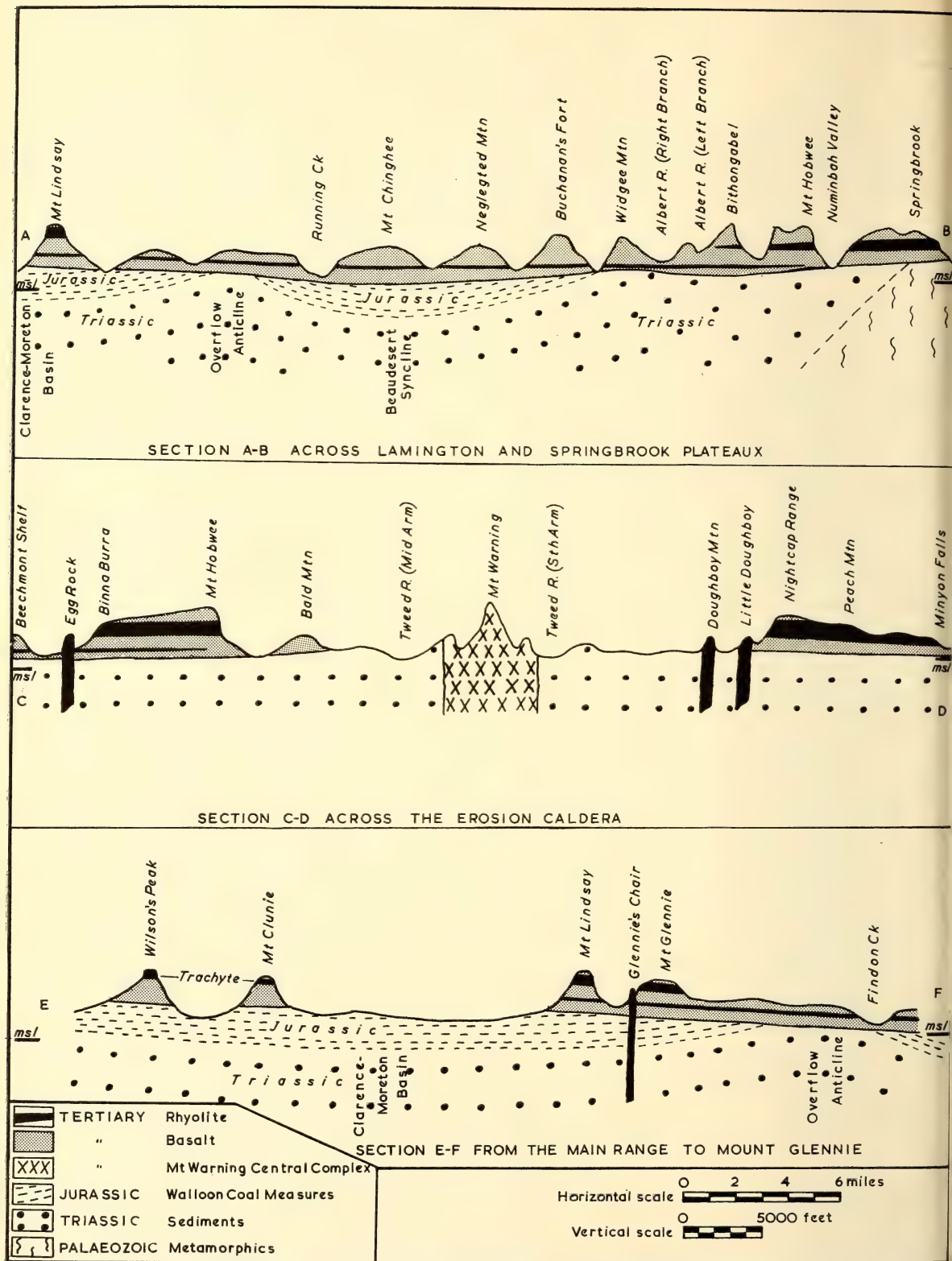
Thus the first lavas from the Mount Warning vent filled a shallow depression coincident with the Beaudesert Syncline and flowed over an undulating surface to the north and west, piling up to the east against the high of Palaeozoic sediments and possibly having limited extent to the south.

THE HILLVIEW RHYOLITE

This name covers a band of agglomeratic tuffs and brecciated rhyolite that is well exposed in the Hillview area in the valley walls of Christmas and Chinghee Creeks. The band shows marked outcrop in the escarpment known as Hillview Cliffs.

In the type area the basal member is up to 50 feet of acid agglomeratic tuff containing boulders of rhyolite up to one foot in diameter. Eastward of the type locality, particularly around the head of Christmas Creek, a considerable amount of accessory boulders is included. These comprise Palaeozoic sediments, granophyre and basalt cobbles to three inches diameter.

The tuff always appears white or buff coloured in outcrop and can be readily traced at the 1,100-foot contour from the type area to the Beechmont Range where it occurs in the 1,000–1,100-foot interval. It is well exposed around Canungra Creek and in the Coomera Valley where it sometimes occurs in cliffs very much resembling those of Triassic sandstones. The tuff there shows well-defined bedding which is accentuated by limonitic staining and contains numerous pebbles of basalt and rhyolite. The band extends to the Canungra



area, where it outcrops at 1,050 feet on the southern slopes of Mount Tamborine.

Overlying this there is up to 150 feet of brecciated and often silicified rhyolite, though in some cases up to 50 feet of basalt may intervene, e.g.: in the Neglected Mountain area. This rhyolite member does not extend eastward of the Canungra Range but west of there it forms a more prominent marker band forming low buff coloured cliffs and changes of slope. Westward from the Richmond Gap the rhyolite becomes bluish white in colour and extremely silicified. This is attributed to leaching by groundwater since all this area is covered by luxuriant rain forest. Further west, at Mount Glennie, the tuff member has thinned out but the rhyolite reaches a maximum thickness of not less than 200 feet and an elevation of 2,000 feet.

Occasionally pitchstone or pitchstone breccia is associated with the rhyolite; up to ten feet of this rock type is exposed in Christmas Creek, under Buchanan's Fort, and in Chinghee Creek.

Both the tuff and the rhyolite can be traced to the vicinity of Mount Lion near Wiangaree. The band occupies the 900–1,000 feet contour interval in that area but it lenses out to the south-east. It is not shown in the face of the erosion caldera nor in any of the high areas south or west of Wiangaree.

No vents have been found, proximal to its outcrop, that could have been responsible for the tuffs and lavas of the Hillview Rhyolite. However, the westerly increase in thickness of the brecciated rhyolite suggests an origin in this direction, whereby the rhyolite plug, Mount Gillies, may have been the effusive centre. Since the tuff is water sorted, of fairly uniform thickness and contains much varied, accessory material, no direct indication can be gained of its source; most likely it also came from the north-west.

THE CHINGHEE CONGLOMERATE

This is a new formational name in print, though the horizon has been referred to as such, verbally, for quite some time. The lacustrine formation consists of alternating beds of coarse argillaceous current bedded sandstones and polymictic conglomerates with boulders up to two feet diameter. Boulders consist of Palaeozoic sediments, rhyolite and granophyre, the last being similar to that of the Mount Barney central stock (Tweedale, 1951). A maximum thickness of one hundred feet is attained at the head of Chinghee Creek, six miles south of Hillview. There, a basalt inter-

calation occurs near the top, indicating that deposition possibly occupied only a short time interval, being merely a torrential accumulation between successive lava flows.

The Chinghee Conglomerate consistently overlies the Hillview Rhyolite, overlaps it to the south-east and outcrops in the caldera escarpment at 800 feet elevation. However, it is only about twenty feet thick at The Pinnacle on the Tweed Range and it lenses out by the southern end of the Wiangaree State Forest, on that range. Argillaceous lenses in the formation contain dicotyledonous leaf impressions, very similar to present-day *Eucalyptus* laminae.

The presence of the coarsest grade of material in the Chinghee Range-Richmond Gap area suggests that this area is adjacent to the principal contributory to the lacustrine depression. It is noted that the area of outcrop of the formation coincides with the southern extension of the Beaudesert Syncline. Thus it might be claimed that a downwarping of the late Mesozoic structure commenced prior to the deposition of the Hillview Rhyolite and that by the time of the Chinghee Conglomerate the subsidence produced sufficient gradient to attract rudaceous sediment of boulder dimensions (see Tertiary Earth Movements). Since the only granophyre in existence in the vicinity is in the central stock of Mount Barney some contribution to the depression from the west must be assumed.

THE BEECHMONT BASALT

Formational status is hereby given to 900 feet of basalt which overlies the Chinghee Conglomerate and is capped by the Binna Burra Rhyolite (see later). The name is taken from the Beechmont Shelf where the basalt and the consecutive acid bands can be seen in the one section on the eastern wall of the Coomera Valley.

In that area the Binna Burra Rhyolite lenses out at 2,000 feet elevation just north of Binna Burra and along the western wall of the Coomera gorge. Thus westward in the Lamington Plateau there is no marker to divide the Beechmont Basalt from the succeeding basalt formation (the Hobwee Basalt) until Glennies Chair is reached, 30 miles distant. On this mountain and on Mount Lindesay nearby, 700 feet of basalt between the Hillview and Mount Lindesay Rhyolites (see later) is considered by the writer to be Beechmont Basalt equivalent.

Similarly, to the south, the Binna Burra Rhyolite ceases at Point Lookout on the Tweed

Range at 1,800 feet elevation. Therefore south of this the only marker is the thinning Chinghee Conglomerate, and, south of its termination in the Wiangaree State Forest there is 3,300 feet of unbroken basalt succession equivalent to the three basalt divisions of the Lamington area.

A unique feature of the formation is the prevalence of lenses of diatomite, shales and conglomerates, the latter containing pebbles to six inches long of granophyre, rhyolite and Palaeozoic sediments. Two such lenses, up to fifteen feet thick, one of which contains dicotyledonous leaf impressions, occur on the road to O'Reilly's Guest House and Tweedale (1951) has described others in the Beechmont and Darlington Ranges.

THE LISMORE BASALT (McElroy, 1959)

This formation comprises half the outcrop area of the shield deposits. Though predominantly basalt, it contains conglomerates, shales, diatomites and opal (the latter at Tintenbar, near Bangalow). Interbedded shales in the Nimbin area have yielded fish remains, as yet undescribed (C. Shipway, Qld. Geol. Surv., verbal communication). The sequence reaches a maximum thickness of 600 feet in the Nightcap Range, where it is overlain conformably by the Nimbin Rhyolite (see later).

The exact relationship between the Lismore Basalt and the Albert and Beechmont Basalts is not established due to the lensing out of the Hillview Rhyolite - Chinghee Conglomerate marker in the Tweed Range and to the disconnection of the overlying Binna Burra and Nimbin Rhyolites. As mentioned previously the Albert Basalt may not have flowed as far as the Nightcap Range; thus the Lismore and Beechmont Basalts may be somewhat equivalents. The included sedimentary beds and the respective thicknesses of the formations support this correlation (see also under Nimbin Rhyolite below).

THE BINNA BURRA RHYOLITE

This is a new formational name for a sequence of aerially distributed tuffs and rhyolite that overlies the Beechmont Basalt in the Binna Burra area, from which place the formation is named. The maximum thickness is 1,000 feet in the central part of the area in the vicinity of the junction of the Ship's Stern and Beechmont Ranges.

Detailed work in this area has been done by Tweedale (1951) who recognized up to 300 feet of lower rhyolite tuff overlain by 700 feet of

rhyolite lava. Locally at Mount Roberts (Binna Burra) the lava is overlain by over 200 feet of upper tuff which is identical with that of the lower member. However, at this point the lava is thinning out and it terminates in the southern end of the Beechmont Shelf.

Tweedale considers that the presence of glass shards in the tuffs is sufficient evidence of aeolian deposition. The present writer agrees and wishes to draw a contrast with the bedded, accessory tuffs of the Hillview Rhyolite sequence.

The tuff members are of very limited areal extent, the lower being somewhat symmetrically distributed about two rhyolite plugs (Egg and Charraboomba Rocks) which are quite obviously the points of origin of the whole Binna Burra Rhyolite sequence. The rhyolite member extends to the Beechmont Shelf in the north, Point Lookout and "The Buggrams" in the south and eastward to the Springbrook Plateau and Mount Cougal. At Springbrook it is underlain locally by obsidian. To the west it thins out in the western wall of the Coomera gorge (Coomera Crevice being incised in the lava) at an elevation of 2,000 feet.

THE MOUNT LINDESAY RHYOLITE

Here again a new name is introduced for a sequence of tuffs, agglomerates, obsidian and rhyolite that forms the cliffs on Mount Lindesay and also on the nearby Mount Glennie. On Mount Lindesay the sequence is 800 feet thick occurring on the southern cliff between 3,100 feet and 3,900 feet elevations. The basal member is 200 feet of rhyolitic tuff and agglomerate (both accidental) which is overlain by obsidian, immediately below the 3,303 feet trigonometrical site. Above this rise spectacular columnar rhyolite cliffs for 600 feet, near the top of which Stephenson (1956) reports some local thin flows of basalt; the succession is capped by basalt of the uppermost basalt sequence (see later).

Similarly on Mount Glennie, tuffs and agglomerates, with very occasional accessory fragments, are overlain by a thick sequence of columnar rhyolite which is capped by basalt. A trigonometrical station (3,169 feet) is situated about 300 feet above the base of the sequence.

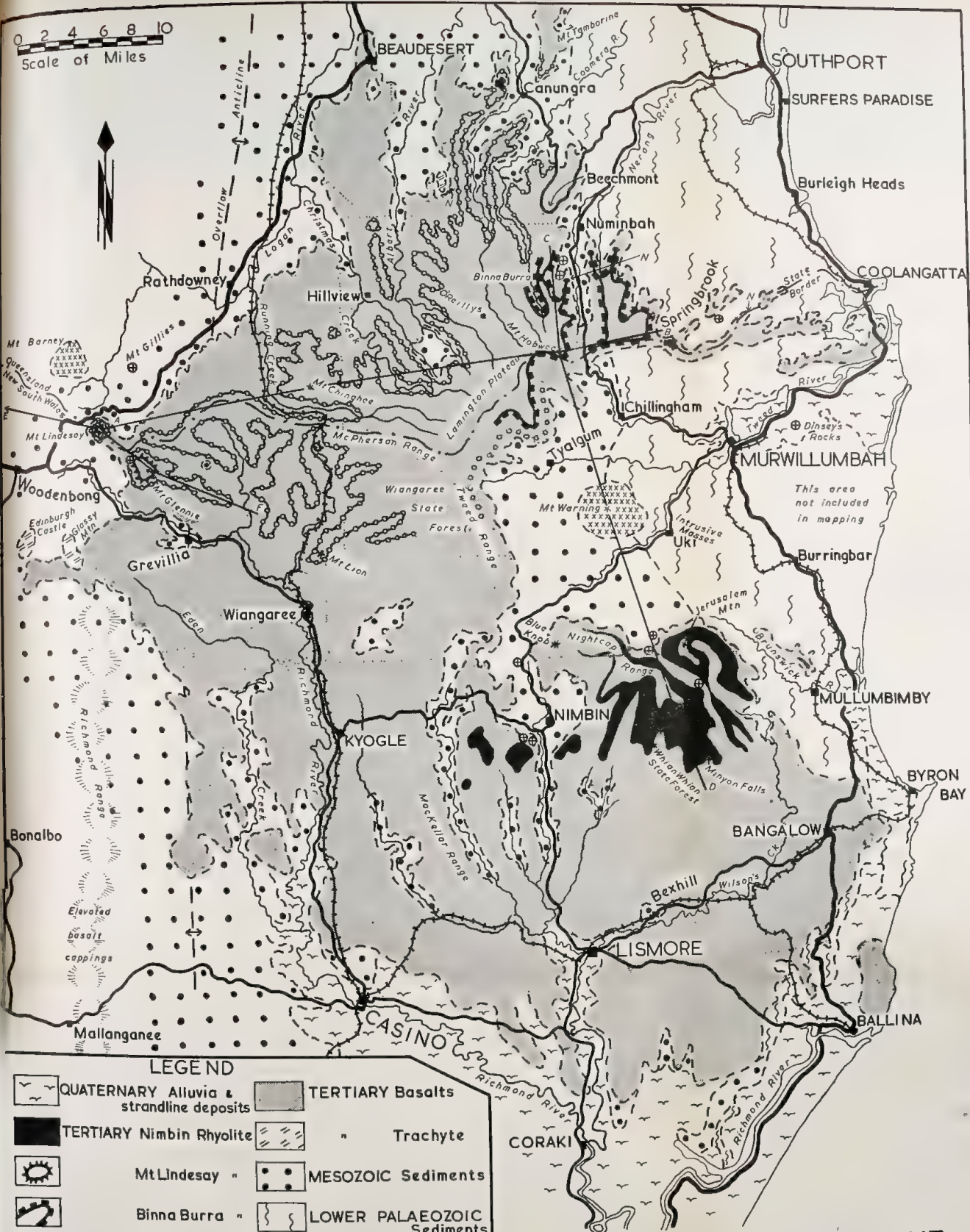
Glennie's Chair, a marked prolongation from the slopes of the mountain, is a rhyolite plug intruding Beechmont Basalt equivalent; this plug is undoubtedly a point of origin of the acid lavas and pyroclastics of the Mount Lindesay Rhyolite sequence.

The writer has no hesitation in correlating the Binna Burra and the Mount Lindesay

0 2 4 6 8 10
Scale of Miles



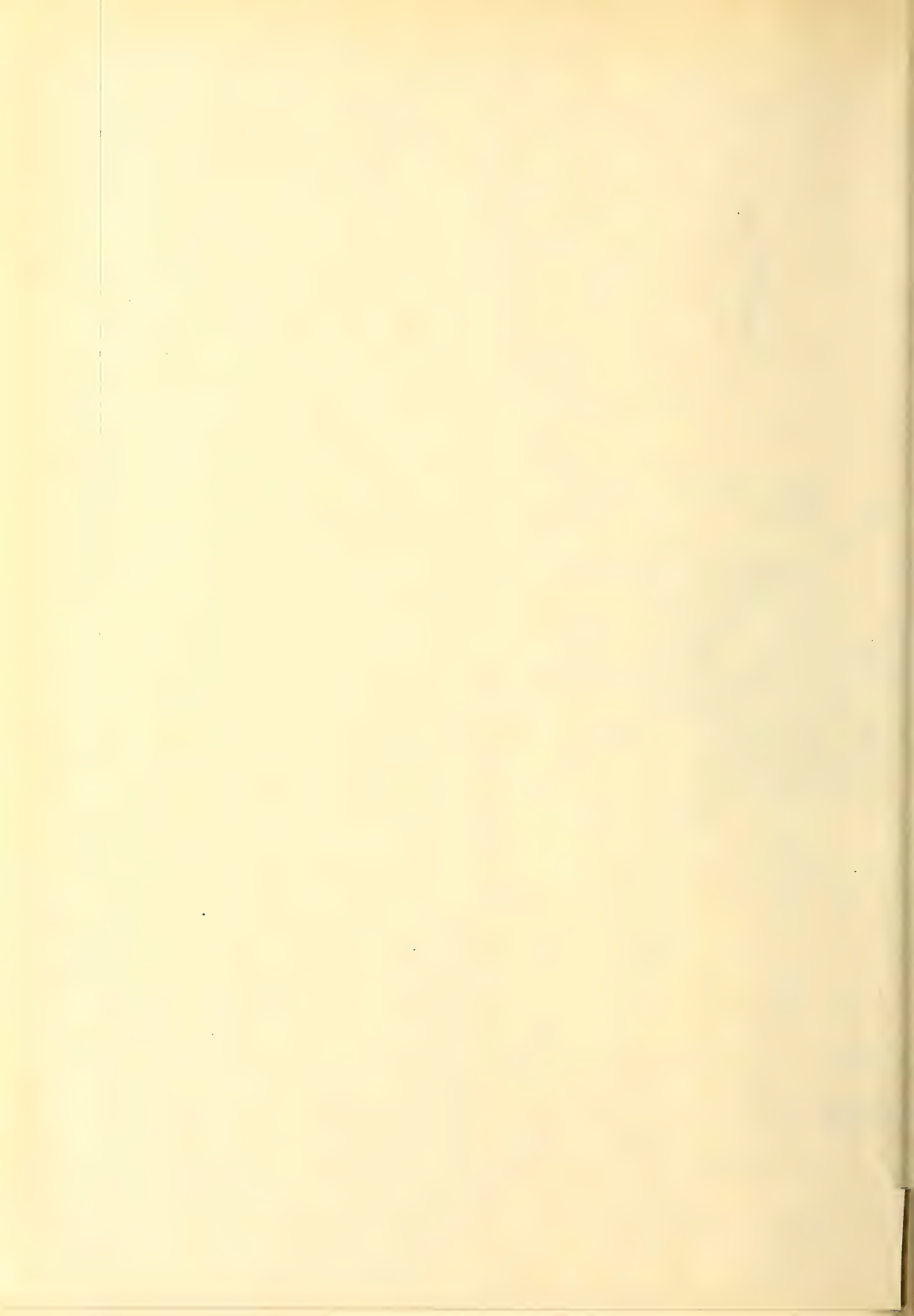
0 2 4 6 8 10
Scale of Miles



LEGEND

- | | | | |
|--|--|--|----------------------------|
| | QUATERNARY Alluvia & strandline deposits | | TERTIARY Basalts |
| | TERTIARY Nimbin Rhyolite | | " Trachyte |
| | Mt Lindsay " | | MESOZOIC Sediments |
| | Binna Burra " | | LOWER PALAEOZOIC Sediments |
| | Chinghee Conglomerate | | Central Complex |
| | Chinghee Cong. & Hillview Rhyolite | | Rhyolite Focus |
| | | | Numinbah Valley Form. |

GEOLOGICAL MAP OF THE MT WARNING VOLCANIC SHIELD



Rhyolites on the basis of similarities in their lithologies, sequences and stratigraphic position in the shield succession. A comparison of stratigraphic columns from Binna Burra and Mount Glennie is as follows:

<i>Binna Burra</i>	<i>Mount Glennie</i>
Hobwee Basalt : 1,960 ft.	Basalt to top
Binna Burra Rhyolite : 800 ft.	Mount Lindesay Rhyolite : 800 ft.
Beechmont Basalt : 900 ft.	Basalt : 700 ft.
Chinghee Conglomerate and Hillview Rhyolite : 100 ft.	Chinghee Conglomerate and Hillview Rhyolite : 200 ft.
Albert Basalt : 400 ft.	Albert Basalt : 800 ft.

Canungra Area

Rhyolite occurs as a capping on Mount Misery, on the Canungra Range, at an elevation exceeding 1,600 feet. Mount Witheren (1,857 feet) to the south shows no evidence of rhyolite, indicating that the Canungra outcrop is a remnant of a local flow probably contemporaneous with the Binna Burra Rhyolite.

THE NIMBIN RHYOLITE (McElroy, 1959)

This formation includes up to 1,300 feet of rhyolite tuffs and lavas with some obsidian that occur between basalts in the Nightcap Range. The sequence is essentially lava; the tuffs and obsidian members occur as local intercalations up to 150 feet thick. The units given the local names "Doroughby Tuff", "Boomerang Creek Obsidian" and "Minyon Falls Rhyolite" by Crook and McGarity (1956) are essentially members of the Nimbin Rhyolite.

The maximum thickness of 1,300 feet is attained in the Minyon Falls-Peach Mountain area on the southern side of the range. On the northern side, 1,000 feet of tuff and rhyolite underlie Jerusalem Mountain between the 1,400 and 2,400-foot contours. The tuff, there, forms columnar residuals similar to "The Steamers" on the Main Range, Queensland.

This sequence forms prominent cliffs to the west of Mullumbimby and at the head of Doon Doon Creek. Further west, it lenses out in the vicinity of Mount Neville at an elevation of 1,400 feet, but it persists south-west to Nimbin, where it forms residual cappings on several small plateaux. The thickness in that area is some 400 feet and the base of the sequence falls to 800 feet elevation.

The presence of several rhyolite plugs within the outcrop area of the sequence indicates a local origin for the Nimbin Rhyolite. Such plugs are Doughboy Mountain and Little

Doughboy in the Jerusalem Mountain area, an unnamed hill at the head of Wilson's Creek and Nimbin Rocks. Lillian Rock, three miles north-west of Nimbin is also a rhyolitic, elongate, plug-like intrusive but there is no evidence that it extruded any lava.

On Section C-D across the erosion caldera there can be seen the dip to the south of the Nimbin Rhyolite. This dip measured on the base of the formation is from 1,400 feet at Jerusalem Mountain to 600 feet at Minyon, a fall of 800 feet in seven miles.

Considering this and also the similarity of lithology between the formation and the Mount Lindesay and Binna Burra Rhyolites and the absence of any contiguous formation analogous to the Chinghee Conglomerate, the writer correlates the Nimbin Rhyolite with the Binna Burra and Mount Lindesay Rhyolites rather than with the Hillview Rhyolite.

Such a correlation necessitates consideration of the relationship between the 1,600 feet of basalt and sediments that occur below the Binna Burra Rhyolite and the 600 feet of similar strata below the Nimbin Rhyolite. The Albert Basalt in thinning from 800 feet in its type area to 300 feet in the Tweed Range appears to have little, if any, representation in the Nightcap Range. Thus the 600 feet of Lismore Basalt in the Nightcap area compares favourably with and is probably the equivalent of the Beechmont Basalt, 900 feet thick in its type area.

THE HOBWEE BASALT

This new formational name is used for 1,960 feet of basalt that overlies the Binna Burra Rhyolite. It typically occurs in the Parish of Roberts, which embraces the Lamington National Park, where its greatest thickness is attained on the state boundary at Mt. Hobwee, this point being the highest on the shield.

Due to the steep scarps developed on the sequence, excellent exposures can be seen of the successive flows of lava, especially on the face of the erosion caldera. Richards counted at least twenty such outpourings, which would indicate an average of just under one hundred feet for each flow. (In the Binna Burra area the Hobwee Basalt coincides with Richards' Upper Division of basic rocks.)

On Mount Lindesay the Hobwee Basalt forms a thin capping (100 feet according to Stephenson, 1956) and the rain forest soil capping Mount Glennie is almost certainly derived from basalt of the same sequence.

THE BLUE KNOB BASALT (McElroy, 1959)

In the Nightcap Range the basalt overlying the Nimbin Rhyolite is about 1,700 feet thick beneath Blue Knob. The exact thickness can only be interpolated since the rhyolite does not extend as far westward as Blue Knob, the highest point on the Range.

The Blue Knob Basalt is probably equivalent to the Hobwee Basalt of the Lamington Plateau.

Correlation between these two disconnected basalt sequences necessarily depends upon the relationship between the underlying Binna Burra and Nimbin Rhyolites (see Nimbin Rhyolite above).

The Blue Knob Basalt is probably also represented on high areas such as the MacKellar Range, east of Kyogle, where 1,600 feet of basalt exists, at least 600 feet of which surmounts the elevation of the nearest Nimbin Rhyolite outcrop (namely 1,200 feet elevation at Nimbin).

Tertiary Earth Movements

It would be expected that the initial outpourings of basalt from the Mount Warning centre would have tended to fill the low areas in the basement and that subsequent flows would have built up a flat cone, individual flows showing very low dips away from the centre. However, the converse is seen in the western area of the shield where in the Tweed (e.g., Bar Mountain) and McPherson Ranges (e.g., the Richmond Gap area) the basalts dip eastward at angles up to two degrees (locally). Two alternative explanations can be proposed for this phenomenon:

- (i) that the basaltic lavas west of Tyalgum and also the interbedded lacustrine deposits had a western source and were deposited on an easterly sloping surface, or
- (ii) that all the basalts issued from the Mount Warning centre and have undergone subsequent folding.

The absence of any large basic eruptive centres to the west supports the second explanation. Furthermore, an examination of cross sections A-B, C-D and E-F shows the prevalence over the whole shield area of a south-easterly dip of strata, suggesting differential earth movement.

Of considerable interest is the relatively uniform band (about 200 feet) of lacustrine deposits comprising the Hillview Rhyolite and the Chinghee Conglomerate. Uniquely, it occupies an elevated sloping aspect (2,000 feet

above sea level at Mount Lindesay falling to 800 feet in the Tweed Range) on the flanks of a volcanic shield. This horizon, which outcrops over an area of 500 square miles and shows complete conformability with the shield basalts, offers the most conclusive evidence of post-shield tectonism. The problem arises

- (I) whether these sediments were deposited in their present aspect and have suffered no subsequent movement, or
- (II) whether they were deposited in a low-lying position and were uplifted together with the other shield components.

The presence of boulders of metamorphic rocks (of Brisbane Schist lithology) together with granophyre boulders (apparently from the western source, Mt. Barney) in the Chinghee Conglomerate and the accessory tuffs of the Hillview Rhyolite is also problematical since

- (a) there is no western source area of Palaeozoic metamorphics within 100 miles and
- (b) the Chinghee Conglomerate rises westward to a height of 1,000 feet above the present (and hence the probable Tertiary) surface of local Palaeozoic rocks.

From (a) it appears that the metamorphic boulders had an eastern origin in the Palaeozoic mass of the Southport-Murwillumbah area. On this basis it would have to be assumed that the Chinghee Conglomerate-Hillview Rhyolite band was deposited on a horizontal surface under lacustrine conditions with contribution from both east and west.

Following (b) the Palaeozoic mass would have had to project to about 2,000 feet elevation during the Tertiary were it to supply material to the Chinghee Conglomerate at its present Mount Lindesay level, i.e. 2,000 feet. However, there is no evidence to assume that the Tertiary surface of the metamorphics rose to heights so exceeding their existing maximal points, i.e. 1,400 feet; it would be more reasonable to assume that the Tertiary sediments were deposited at low altitude and were subsequently uplifted to their present position. This conclusion would satisfy arguments (ii) and (II) above.

Due to the existence of the lacustrine sediments so close (16 miles) to the coastline, the writer considers it most probable that they were deposited at an elevation not much above the prevailing Tertiary sea level. Such an accumulation of rudaceous strata in a large, low lying, near coastal lacustrine depression, associated with basaltic lava flows, would

present a strikingly similar environment and succession to that shown by Tertiary deposits in the Brisbane and Bundaberg areas (see *Age and Correlation of Shield Components*). Thus, considering this and the above evidence, it appears that considerable post-shield uplift of the order of 2,000 feet has occurred in the Mount Lindesay area and possibly over 1,000 feet in the Lamington Plateau area.

It would be impossible to make any assessment of actual uplift in any particular area, but it may strengthen the case for relative uplift to quote the variations in the bases of the upper rhyolite sequences

Mt. Lindesay Rhyolite :	3,100 ft.
Binna Burra Rhyolite :	2,000 ft.
Nimbin Rhyolite (north) :	1,400 ft.
Nimbin Rhyolite (south) :	600 ft.

Of course the significance of these elevations depends largely upon the correlation of the three sequences. Nevertheless, the figures present attractive data, however superficial, for the proposal of late Tertiary differential folding of the shield.

Age and Correlation of Shield Components

The presence of dicotyledonous leaf impressions in the Numinbah Valley Formation indicates that the whole shield is post-Middle Cretaceous, most probably Tertiary in age.

Bryan and Jones (1946) placed the Lamington "Series" in the Pliocene, maintaining that the sequence was in age post-laterite, to which phenomenon they assigned a Miocene age. However, the presence of large areas of red-earth residual soils (Bryan, 1939) on the plateaux of Beechmont, Springbrook and Tamborine and of laterite on the latter leaves little doubt that the basalts of the shield have been subjected to intense lateritization. However, the age of this process is much in doubt and cannot really be confined to a more specific age assignment than Miocene to Pliocene. The writer therefore wishes to attack the problem along entirely different lines.

In the Brisbane area, where the writer has recently studied interbedded Tertiary lavas and sediments, the sequence argillaceous sediments-basalt-rudaceous sediments in ascending order, is pronounced over an area extending from Petrie to Ipswich and covering four separate Tertiary basins. Thus, in the Lamington Group when the writer was confronted with the same sequence of strikingly similar lithological

components, the possibility of some form of correlation could not be overlooked.

The Numinbah Valley Formation has a lithology and contains a trifid venated dicotyledonous leaf flora similar to that of the Darra Formation in the Brisbane area and the Redbank Plains Formation of that type area. The maximum thickness of the basalt overlying the Redbank Plains Formation is 1,000 feet (writer's calculation) at Redbank Plains, while that of the Albert Basalt is 800 feet. At Redbank Plains the basalt is overlain by trachyte and fifty feet of boulder conglomerates, while in the Lamington sequence the Albert Basalt is succeeded by rhyolite and up to one hundred feet of boulder conglomerates, namely the Chinghee Conglomerate. The Beechmont Basalt, the upper rhyolite sequence and the Hobwee Basalt do not appear to have any equivalent in south-east Queensland except possibly in the Main Range (see section E-F).

According to Hills (1934) the fish *Phareodus queenslandicus* which is found in the Redbank Plains Formation and the Archerfield basalt (Cribb, McTaggart and Staines, 1960) at Brisbane, indicates an Eocene, probably Oligocene, age for those strata. The present writer therefore suggests an Eocene-Oligocene age for the Numinbah Valley Formation and the Albert Basalt.

Since the remainder of the sequence is 2,800 feet thick and is composed of one major and several minor sedimentary intervals, two thick basalt sequences of possibly thirty separate flows and two rhyolite episodes, it is possible that deposition of the shield volcanics lasted till late in the Tertiary and that the upper part, at least, of the Hobwee Basalt is Pliocene in age. Indeed, much of it seems to be post-lateritic, a feature which may be significant.

The age of the alkaline and granophyre plugs to the west cannot be any more accurately dated than Cretaceous-Eocene, i.e. post-Walloon Coal Measures-pre-Albert Basalt. Since there are plugs and flows of andesite, rhyolite and trachyte of Late Jurassic (post-Walloon Coal Measures)-Cretaceous age in the Maryborough Basin, 250 miles to the north, it cannot be discounted that the intrusives of the Woodenbong area may be Cretaceous in age.

Stevens (verb. com. 1960) has recently investigated the Main Range area between Mount Superbus and Cunningham's Gap, where he has noted two trachyte lava and pyroclastic bands. The cross section E-F from Mount Glennie to Wilson's Peak on the Main Range

encourages a correlation between the trachyte bands on Wilson's Peak and Mount Clunie and the Mount Lindesay Rhyolite. It is therefore not impossible that a more definite relationship may be established upon completion of mapping of the Main Range.

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A New Study of the Hawkesbury Sandstone: Preliminary Findings

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ABSTRACT—The Triassic Hawkesbury Sandstone has a more restricted distribution than previously thought and large areas formerly mapped as Hawkesbury Sandstone, including the Blue Mountains cliff escarpments and much of the region north of the Hawkesbury River, are in reality Narrabeen Group. The Hawkesbury Sandstone is a uniform formation and shows little change in appearance or composition throughout its entire area of deposition. No basin structure existed during the time of deposition. The edge of the continental mass was in the same position as it is today, some 15 miles to the east of the present coastline. The direction of deposition was remarkably constant throughout the entire formation, being always to the north-east.

The Triassic Hawkesbury Sandstone, which outcrops in the Sydney Basin, New South Wales, has been studied in local areas by many geologists but not until this present study was commenced was an attempt made to study the entire formation as a single project.

Detailed investigation of the Hawkesbury Sandstone has revealed that it is an extremely uniform formation throughout its entire area of deposition and it shows little variation in appearance or composition.

The formation is composed of discontinuous layers of highly cross-bedded quartz sandstone which have an argillaceous cement. The cement is generally illite and is probably of detrital origin. The grain size of the sandstone varies from fine to very coarse, with medium to coarse grained sand being the most common. Graphite is a common accessory mineral and is found throughout the entire formation. Scattered pebbles up to $\frac{1}{2}$ inch in diameter are common, but layers of conglomerate are rare. The composition of the scattered pebbles and conglomerate layers is always over 90% quartz and pebble counts with 98-99% quartz content are common. The cross-bedding is almost always of the forset type with other types of cross-bedding and scour and fill sedimentary structures being much less common.

There are a few thin, usually less than 5 feet, layers of clay which are generally not traceable laterally more than a few hundred feet.—The thickest and most extensive shale layers occur in the French's Forest-Brookvale area and in the Lucas Heights area where they are up to 30 feet in thickness and are traceable for about 1 mile. These thick shale layers are located in the upper quarter of the formation. In the coastal cliff section in the Sydney area layers of black shale up to 15 feet in thickness are found; these black shales have a high organic content and commonly contain syngenetic pyrite.

The result of over 4,000 current direction readings shows that the direction of deposition was remarkably constant throughout the entire formation being always in a north-easterly direction.

There is no problem in distinguishing the Hawkesbury Sandstone from the overlying Wianamatta shale and the boundary indicated for these two formations on the Sydney and Wollongong 4-mile geological maps remains basically unchanged.

More difficulty was encountered in distinguishing the Hawkesbury Sandstone from the underlying Narrabeen Group, but the present studies have indicated that the base of the Hawkesbury Sandstone can be separated from the underlying Narrabeen Group by the following criteria, which are observed in the Narrabeen Group:

1. Increased number and thickness of clay units.
2. Increased argillaceous content of the sandstone, making it much more friable.
3. Decrease in forset type cross-bedding.
4. The development of interbedded sandstone and clay layers which are flat lying and which can be traced laterally over long distances.
5. Increase in lenticular sandstone units and in scour and fill type structures.
6. In the northern part of the Sydney Basin conglomerate layers become much more common and the quartz content of the pebbles drops from over 90% to less than 40%.

The thicker clay layers and more argillaceous sandstones of the Narrabeen Group commonly weather to form flat areas that are capable of supporting small farms and are commonly developed as farming areas. The Hawkesbury

Sandstone, on the other hand, seldom weathers to form farmable-type country and, except in the Sydney Metropolitan area, is generally uninhabited.

Detailed investigation of the Hawkesbury Sandstone has shown that its distribution is much more restricted in area than had previously been mapped by earlier workers. The largest change in distribution of the Hawkesbury Sandstone occurs in the northern and western parts of the Basin. The new State Geological Map now being prepared by the New South Wales Geological Survey shows the modified boundary of the Hawkesbury Sandstone.

In the Blue Mountains the western-most outcrop of the Hawkesbury Sandstone is at Woodford, all of the area west of this point, including the cliffs of the Blue Mountains escarpments, are part of the Narrabeen Group. Mount Tomah, Mount Wilson and Mount Irvine areas mark the north-western-most extent of the Hawkesbury Sandstone, all of the large sandstone cliffs in the Lithgow, Newnes, Glen Davis and Rylstone areas are Narrabeen Group. On the Putty Road, Grassy Hill marks the northern-most boundary of the Hawkesbury Sandstone except for a complete section which is preserved underneath the Wianamatta and the basalt capping of Mt. Yengo. The basalt capping at Mt. Warrawolong overlies the Hawkesbury and marks the north-eastern limit of the Hawkesbury Sandstone.

North of the Hawkesbury River the distribution of the Hawkesbury Sandstone is somewhat restricted. Along the Pacific Highway between the Hawkesbury River and Gosford there are no outcrops of Hawkesbury Sandstone except for a few small remnants. The area traversed by the highway is part of the large Kulnura anticlinal structure which is plunging to the south, from which most of the Hawkesbury Sandstone has been removed by erosion. The area between Calga, Peat's Ridge, Central Mangrove and Kulnura is entirely Narrabeen (except for one small remnant of Hawkesbury Sandstone north of Calga), and is located along the crest of this structure. Along the limb of the structure to the west, along the Old Great Northern Road and to the east in the Main Range the Hawkesbury Sandstone outcrops.

The distribution of the Hawkesbury Sandstone in the southern part of the Sydney Basin is basically the same as indicated on the Wollongong 4-mile geological map except that the Narrabeen Group outcrops in the canyons near the Nepean, Avon, Cataract and Woronora Dams. The southern limit of the Hawkesbury Sandstone is the escarpment overlooking Kangaroo Valley near Fitzroy Falls.

A more detailed and much more comprehensive paper dealing with the stratigraphy, structure and petrology of the Hawkesbury Sandstone will be published when this project is completed.

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On the Number of Collisions to Slow Down Neutrons from High Speeds

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ABSTRACT—Explicit forms for the distribution of the number of collisions to cross a finite energy interval are given for Hydrogen with absorption, and a single nuclear species without absorption. In the latter case a moment generating function equation is derived. The case of a single nuclide with constant absorption is summarised, and a general equation for the higher moments of the distribution of the number of collisions to escape a narrow resonance for a given initial collision in the resonance region found.

1. Introduction

In Monte Carlo investigations of the slowing down of neutrons, a priori estimate of the average computing time per neutron cannot be made without some knowledge of the distribution of the number of collisions suffered by a neutron as its speed drops from the high initial value to thermal speeds. The investigator needs such an estimate to determine the amount of computing time that must be bought and the economic size of his sample of neutron case-histories.

A more convenient variable than energy or speed is the “lethargy”, which is defined by

$$u = \ln (E_0/E)$$

where E_0 is the initial (source) energy of the neutron. Use of this variable leads to considerable simplification in many formulae. At the source energy, a neutron has zero lethargy, and as the neutron’s energy decreases, its lethargy increases.

If scattering is assumed to be spherically symmetric in the centre-of-mass system, then the mean number of collisions $N_1(u)$ suffered by a neutron to achieve a lethargy greater than or equal to u in an infinite homogeneous non-absorbing system containing one nuclear species of relative mass A , is given by the “renewal equation”:

$$N_1(u) = \int_0^u f(u') \{N_1(u-u') + 1\} du' \dots\dots\dots (1)$$

where

$$f(u) = H(u)H(-\log \alpha - u)e^{-u}/(1-\alpha), \dots\dots\dots (2)$$
$$\alpha = (A-1)/(A+1)^2$$

and $H(x)$ is the Heaviside unit function.

De Marcus (1959) has proposed a solution of (1) in terms of the Placzek function. De Marcus’ solution includes the initial collision at lethargy 0, which is not counted in equation (1). If it is desired to include this collision, equation (1) must be replaced by

$$N_1(u) = 1 + \int_0^u f(u')N_1(u-u')du'.$$

We will not count the initial collision in the determination of $N_1(u)$ or the other moments of the distribution of the number of collisions.

An alternative form of the solution which is more useful for small values of u can be found using Teichmann’s results (Teichmann, 1960).

The purpose of this paper is to present certain results concerning the distribution of the number of collisions to cross a finite lethargy interval. The following symbols will be used :

$$u_m = -\ln \alpha,$$

$pr(n, u)$ = the probability that a neutron escapes to lethargies above u after exactly n collisions at lethargies below

$$p(u) = \sum_0^{\infty} pr(n, u)$$

= the total escape probability

$$Pr(n, u) = pr(n, u) / p(u)$$

= the probability that a neutron has exactly n collisions at lethargies below u , given that the neutron does escape

$1 - h(u)$ = the probability of absorption in a collision at lethargy u .

Thus, if $1 - h(u) = 0$, then $p(u) = 1$, and $Pr(n, u) = pr(n, u)$.

Note also that if $h(u)$ is a constant, c , then for $n > 0$

$$pr(n, u) = c \int_0^u f(u') pr(n-1, u-u') du' \quad \dots \dots \dots (3)$$

2. Hydrogen with Absorption

The probability that a neutron slowing down in hydrogen has collisions in the elementary intervals $\Delta u_1, \Delta u_2, \dots, \Delta u_n$, about the lethargies u, u_2, \dots, u_n below u , and then escapes to lethargies above u , is:

$$h(0)f(u_1) \left\{ \prod_1^{n-1} f(u_{i+1}-u_i)h(u_i) \right\} h(u_n) \int_u^{\infty} f(u_{n+1}-u_n) du_{n+1} \Delta u_1 \Delta u_2 \dots \Delta u_n,$$

so

$$\begin{aligned} pr(n, u) &= h(0) \int_0^u \int_{u_1}^u \dots \int_{u_{n-1}}^u \int_u^{\infty} f(u_1) \prod_1^n f(u_{i+1}-u_i) h(u_i) du_1 du_2 \dots du_{n+1} \\ &= h(0) e^{-u} \left(\int_0^u h(u') du' \right)^n / n'. \quad \dots \dots \dots (4) \end{aligned}$$

$$\text{Summing on } n \text{ gives } p(u) = h(0) e^{-u} \exp \left(\int_0^u h(u') du' \right) \quad \dots \dots \dots (5)$$

This last result is well-known but is usually derived from the differential equation for the collision density.

Equations (4) and (5) yield

$$Pr(n, u) = \exp \left(- \int_0^u h(u') du' \right) \cdot \left(\int_0^u h(u') du' \right)^n / n'.$$

so $Pr(n, u)$ is Poissonian with mean and variance equal to $\int_0^u h(u') du'$.

3. Single Nuclear Species without Absorption

The energy distribution $D(n, u)$ of neutrons which have suffered just n collisions is (Marshak, 1947, p. 198):

$$D(n, u) = \{e^u (1-\alpha)^n (n-1)!\}^{-1} \sum_{k=0}^n (-1)^k \binom{n}{k} (u - k u_m)^{n-1} H(u - k u_m) \quad \dots \dots \dots (6)$$

so (recalling that $p(u)$ is in this case unity):

$$\begin{aligned} \sum_0^{n-1} Pr(k, u) &= \int_u^{\infty} D(n, u') du' \\ &= \{(1-\alpha)^n (n-1)!\}^{-1} \sum_{k=0}^n (-1)^k \binom{n}{k} e^{-k u_m} \Gamma(u, k, n) \quad \dots \dots \dots (7) \end{aligned}$$

where

$$\Gamma(u, k, n) = \int_{(u - ku_m)H(u - ku_m)}^{\infty} e^{-y} y^{n-1} dy.$$

If $E(e^{kt}, u)$ is defined by

$$E(e^{kt}, u) = \sum_0^{\infty} e^{kt} Pr(k, u),$$

then from equation (3)

$$E(e^{kt}, u) = \int_u^{u_m} f(u') du' + e^t \sum_1^{\infty} \int_0^u f(u') Pr(k-1, u-u') e^{(k-1)t} du'$$

that is

$$E(e^{kt}, u) = \int_u^{u_m} f(u') du' + e^t \int_0^u f(u') E(e^{kt}, u-u') du' \quad \dots \dots \dots (8)$$

An equation for the r th moment $N_r(u)$ of $Pr(n, u)$ can be obtained by differentiating the last equation r times with respect to t , and then setting t equal to zero, thus :

$$N_r(u) \sum_0^r \binom{r}{k} \int_0^u f(u') N_k(u-u') du' \quad \dots \dots \dots (9)$$

Equation (8) generalises the renewal equation (1)

The second moment $N_2(u)$ is given by

$$N_2(u) = 2N_1(u) + \int_0^u f(u') N_2(u-u') du' - \int_0^u f(u') du'.$$

Taking Laplace transforms, substituting $\mathcal{L}(N_1(u))$ for

$$\frac{\mathcal{L}(f(u))}{s\{1 - \mathcal{L}(f(u))\}},$$

and inverting gives

$$N_2(u) = \frac{1}{\pi i} \int_{a-i\infty}^{a+i\infty} \frac{(1-\alpha)(1+s)(1-\exp[-u_m(1+s)])e^{su}}{s\{(1-\alpha)(1+s)-1+\exp[-u_m(1+s)]\}^2} ds - N_1(u)$$

Smith (1959) has shown that for a wide class of distribution functions, the asymptotic variance is given by

$$N_2(u) - (N_1(u))^2 = \frac{\mu_2 - \mu_1^2}{\mu_1^3} u + \frac{5\mu_2^2}{4\mu_1^4} - \frac{2\mu_3}{3\mu_1^3} - \frac{\mu_2}{2\mu_1^2} + 0(1)$$

where $\mu_i = \int_0^{\infty} u^i f(u) du$.

From (2), we have

$$\mu_1 = \int_0^{u_m} u e^{-u} du / (1-\alpha) = \xi$$

$$\mu_2 = \int_0^{u_m} u^2 e^{-u} du / (1-\alpha) = 2\xi - \alpha (\ln \alpha)^2 / (1-\alpha)$$

$$\mu_3 = \int_0^{u_m} u^3 e^{-u} du / (1-\alpha) = 6\xi - 3\alpha (\ln \alpha)^2 / (1-\alpha) + \alpha (\ln \alpha)^3 / (1-\alpha)$$

in accordance with the general relation

$$\mu_k = (-1)^{k+1} \alpha (\ln \alpha)^k / (1-\alpha) + k \mu_{k-1}, \quad k \geq 1.$$

The asymptotic variance can, therefore, be written as a linear function of the asymptotic mean

$$\{\sigma^2(u)\}_{\text{asymptotic}} = a u / \xi + b = a \{N_1(u)\}_{\text{asymptotic}} + d.$$

This result may be derived independently from the fact that all roots of

$$(1-\alpha)(1+S) - 1 + \exp[-u_m(1+S)] = 0$$

are simple with negative real parts, apart from zero.

An alternative expression for the second moment which is more useful for small values of u can be found as follows :

$$\begin{aligned}\mathcal{L}(N_2(u)) + \mathcal{L}(N_1(u)) &= 2 \frac{(1-\alpha)(1+s)(1-\exp[-u_m(1+s)])}{s\{(1-\alpha)(1+s)-1+\exp[-u_m(1+s)]\}^2} \\ &= \frac{2(1+s)(1-\alpha e^{-u_m s})}{s(1-\alpha)(s-\beta)^2} \sum_0^\infty (k+1) \frac{(-\beta)^k}{(s-\beta)^k} e^{-ksu_m}\end{aligned}$$

where (borrowing Teichmann's notation)

$$\beta = \frac{\alpha}{1-\alpha}.$$

Inversion term-by-term gives

$$\begin{aligned}N_2(u) + N_1(u) &= \frac{2}{1-\alpha} \sum_0^\infty \frac{(-\beta)^k}{k!} \{e^{\beta(u-ku_m)}(u-ku_m)^{k+1}H(u-ku_m) \\ &\quad - [\alpha e^{\beta(u-[k+1]u_m)}](u-[k+1]u_m)^{k+1}H(u-[k+1]u_m) \\ &\quad + \int_0^u [e^{\beta(u'-ku_m)}](u'-ku_m)^{k+1}H(u'-ku_m)du' \\ &\quad - \alpha \int_0^u [e^{\beta(u'-[k+1]u_m)}](u'-[k+1]u_m)^{k+1}H(u'-[k+1]u_m)du'\}\end{aligned}$$

In particular, for $0 \leq u \leq u_m$

$$N_2(u) + N_1(u) = \frac{2}{(1-\alpha)} \left\{ \frac{e^{\alpha u} u}{\alpha} - \frac{e^{\beta u}}{\beta^2} + \frac{1}{\beta^2} \right\}. \quad (10)$$

4. Single Nuclear Species with Constant Probability of Absorption

One application of this case is as a check in Monte Carlo programmes. It can also be used to obtain an approximate solution of the slowing-down problem in a medium with a "slowly varying" ratio of absorption cross-section to total cross section. (See, for example, Dresner, 1960.) It is now convenient to redefine $E(e^{kt}, u)$ by

$$E(e^{kt}, u) = \sum_0^\infty e^{kt} p_r(k, u)$$

so that

$$E(e^{kt}, u) = c \int_u^{u_m} f(u') du' + e^{tc} \int_0^u f(u') E(e^{kt}, u-u') du' \quad (11)$$

where c is the constant probability of scattering. If t is set equal to zero in the last equation, we obtain an equation for $p(u)$:

$$p(u) = c \int_u^{u_m} f(u') du' + c \int_0^u f(u') p(u-u') du'$$

which gives, on taking Laplace transforms:

$$\mathcal{L}(p(u)) = \frac{c([1-\alpha][1+s] - [1 - e^{-u_m(1+s)}])}{s([1-\alpha][1+s] - c[1 - e^{-u_m(1+s)}])} \quad (12)$$

The zeros of

$$(1-\alpha)(1+s) - c(1 - e^{-u_m(1+s)})$$

are still simple unless

$$c = \frac{1-\alpha}{u_m} \quad (13)$$

in which case it follows obviously that -1 is a double root. However, as -1 is also a root of the numerator of $\mathcal{L}(p(u))$, all the poles of the latter are simple. Also, for all c ($0 \leq c \leq 1$), the roots still have negative real parts, for if c is not one, zero is not a root, and any other root $x+iy$ must satisfy

$$y \frac{1-\alpha}{c\alpha \cdot \alpha^x} = \sin u_m y$$

For non-negative x , we have

$$\frac{1-\alpha}{c\alpha \cdot \alpha^x} \geq u_m$$

and hence the two curves

$$f_1(y) = y \frac{1-\alpha}{c\alpha \cdot \alpha^x}, \quad f_2(y) = \sin u_m y, \quad x \geq 0$$

intersect only at the origin.

It follows that if c satisfies equation (13) and the poles of the right-hand side of equation (12), apart from -1 , are denoted by ω_i , then

$$p(u) = e^{-u} \frac{1-c}{cu_m} + \sum_i \frac{[1-\alpha][1+\omega_i] - [1-e^{-u_m(1+\omega_i)}]}{\omega_i[1-\alpha-cu_me^{-u_m(1+\omega_i)}]} e^{\omega_i u}$$

If -1 is not a pole, the first term on the right-hand side does not appear.

For the purpose of checking Monte Carlo programmes, it is also useful to have a formula for $p(u)$ suitable for evaluation at small u . Proceeding as was done with $N_2(u)$ above yields

$$p(u) = c \{ 1 - (1-c) \sum_0^{\infty} (-u)^k [M(k, u) - \alpha M(k+1, u)] \} \dots \dots \dots (14)$$

where $M(k, u) = (k!)^{-1} H(u - ku_m) \int_{ku_m}^u e^{-\lambda x} x^k dx$,

$$\lambda = 1 - \frac{c}{1-\alpha},$$

and

$$\mu = \frac{c\alpha}{1-\alpha}.$$

Once $p(u)$ has been found, the r th moment of $Pr(n, u)$ can be determined by differentiating equation (11) r times with respect to t , setting t equal to zero, solving the resulting integral equation for

$$\left(\frac{\partial^r E(e^{ht}, u)}{\partial t^r} \right)_{t=0},$$

and dividing the solution by $p(u)$.

If it is remembered that the initial collision is not counted in the right-hand side of equation (6), it is easy to see from (7) that for constant $h(u)$,

$$pr(n, u) = c^{n+1} \int_0^u \{ D(n+1, u') - D(n, u') \} du',$$

and hence $Pr(n, u)$ is easily determined.

An expression for the collision density may be derived as was equation (14).

5. The Number of Collisions to Escape Absorption in a Narrow Resonance

When $h(u)$ is not constant but varies widely as in all physical cases, the Laplace transform is no longer of very much use. However, suppose a neutron has had a collision at lethargy u_0 , and that this is its first collision in the region of a narrow resonance less than one collision width wide. It will be shown that the average number of collisions necessary for the neutron to escape (not counting the initial one) may still be determined.

It is convenient here to return to energy co-ordinates and to redefine some symbols correspondingly. Let E_0 be the energy corresponding to u_0 , and $E_F (\geq \alpha E_0)$ be the lower cut-off energy of the resonance. By the usual differential method, it can be shown that if a neutron has had a collision at E_0 , then the probability $p(E_0, E_F)$ that the neutron escapes is:

$$p(E_0, E_F) = \frac{E_F}{E_0} h(E_0) \exp \left[\int_{E_F}^{E_0} \frac{h(E)}{E(1-\alpha)} dE \right] \left\{ 1 - \frac{\alpha}{E_F(1-\alpha)} \int_{E_F}^{E_0} \exp \left[- \int_{E_F}^E \frac{h(E')}{E'(1-\alpha)} dE' \right] dE \right\}$$

where $h(E)$ is the probability of non-absorption at energy E .

To simplify later expressions, let $g(E)$ and $f(E)$ be defined by

$$f(E) = \frac{h(E)}{E(1-\alpha)}$$

$$g(E) = (E_F - \alpha E) f(E).$$

Let $pr(n, E_0)$ denote the probability that the neutron escapes from the resonance after exactly n collisions, not counting the initial one at E_0 , so that

$$pr(0, E_0) = g(E_0)$$

$$pr(n, E_0) = \int_{E_F}^{E_0} \int_{E_F}^{E_1} \dots \int_{E_F}^{E_{n-1}} \prod_0^{n-1} f(E_i) g(E_n) dE_1 \dots dE_n, n > 0.$$

$$\sum_0^{\infty} pr(n, E_0) = p(E_0, E_F) \dots \dots \dots (15)$$

and

$$\frac{\partial}{\partial E_0} \{pr(n, E_0)/f(E_0)\} = pr(n-1, E_0), \quad n > 0. \quad (16)$$

Let $Pr(n, E_0)$ be the ratio of $pr(n, E_0)$ to $p(E_0, E_F)$.

We wish to determine

$$N_1(E) = \sum_0^{\infty} n Pr(n, E_0) \\ = f(E_0) S(E_0)/p(E_0, E_F), \text{ say.} \quad (17)$$

(Equation (17) defines $S(E_0)$.)

From equations (16), (17) and the definition of $Pr(n, E_0)$,

$$\frac{\partial}{\partial E_0} \{S(E_0)\} = (N_1(E_0) + 1)p(E_0, E_F). \quad (18)$$

while from equations (15) and (16)

$$p(E_0, E_F) = g(E_0) + f(E_0) \int_{E_F}^{E_0} p(E, E_F) dE,$$

so that

$$\frac{\partial}{\partial E_0} p(E_0, E_F) = -\alpha f(E_0) + p(E_0, E_F) \left(\frac{f'(E_0)}{f(E_0)} + f(E_0) \right) \quad (19)$$

Combination of equations (17), (18) and (19) gives

$$\frac{\partial}{\partial E_0} \{N_1(E_0)\} = f(E_0) + \alpha N_1(E_0) f(E_0)/p(E_0, E_F)$$

which yields, after some reduction

$$N_1(E_0) = \left\{ 1 - \frac{\alpha}{E_F(1-\alpha)} \int_{E_F}^{E_0} \exp \left[- \int_{E_F}^E f(E') dE' \right] dE \right\}^{-1} \\ \times \left\{ \int_{E_F}^{E_0} f(E) \left(1 - \frac{\alpha}{E_F(1-\alpha)} \int_{E_F}^E \exp \left[- \int_{E_F}^{E'} f(E') dE' \right] dE' \right) dE \right\} \quad (20)$$

If the resonance is very narrow, we can write

$$N_1(E_0) \approx \int_{E_F}^{E_0} \frac{h(E)}{E(1-\alpha)} dE,$$

a result exact at all energies for Hydrogen.

Similarly, the higher moments of $Pr(n, E_0)$ can be shown to satisfy

$$\frac{\partial}{\partial E_0} \{N_r(E_0)\} = f(E_0) \sum_0^{r-1} \binom{r}{k} N_k(E_0) + \alpha f(E_0) N_r(E_0)/p(E_0, E_F).$$

In particular, the second moment may be written

$$N_2(E_0) \int_{E_F}^{E_0} f(E) \{2N_1(E) + 1\} \exp \left[\alpha \int_E^{E_0} \frac{f(E')}{p(E', E_F)} dE' \right] dE$$

If $h(E)$ is put equal to one, this reduces to equation (10), after transforming to lethargy units with zero lethargy corresponding to E_0 , and substituting for N_1 .

The author wishes to express his thanks to Associate Professor A. Keane for his generous assistance and advice.

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Minor Planets Observed at Sydney Observatory during 1960

W. H. ROBERTSON
Sydney Observatory, Sydney

The following observations of minor planets were made photographically at Sydney Observatory with the 9-inch Taylor, Taylor and Hobson lens. Observations were confined to those with southern declinations in the *Ephemerides of Minor Planets* published by the Institute of Theoretical Astronomy at Leningrad.

On each plate two exposures, separated in declination by approximately 0'.5, were taken with an interval of about 20 minutes between them. The beginnings and endings of the exposures were automatically recorded on a chronograph by a contact on the shutter.

Rectangular coordinates of both images of the minor planet and three reference stars were measured in direct and reversed positions of the plate on a long screw measuring machine. The usual three star dependence reduction, retaining second order terms in the differences of the equatorial ordinates, was used. Proper motions, when the were available, were applied to bring the star ositions to the epoch of the plate. Each expo ure was reduced separately

in order to provide a check by comparing the difference between the two positions with the motion derived from the ephemeris. The tabulated results are means of the two positions at the average time except in cases 983, 991, 1007, 1060, 1089, 1111, 1114, where each result is from only one image, due to a defect in the other exposure or a failure in timing it. No correction has been applied for aberration, light time or parallax but in Table I are given the factors which give the parallax correction when divided by the distance. The serial numbers follow on from those of a previous paper (Robertson, 1960). The observers named in Table II are W. H. Robertson (R), K. P. Sims (S) and H. W. Wood (W). The measurements were made by Miss E. Kaberry, Miss K. Molloy and Mrs. M. Wilson, who have also assisted in the computation.

Reference

ROBERTSON, W. H., 1960. *J. Proc. Roy. Soc. N.S.W.*, 94, 71; *Sydney Observatory Papers* No. 38.

TABLE I

No.	1960	U.T.	Planet	R.A. (1950.0)			Dec. (1950.0)			Parallax Factors	
				h	m	s	°	'	"	s	"
941	Aug.	30.61672	5 Astraea	23	18	30.98	—	7	48	04.3	+0.02 —3.8
942	Sep.	6.56623	5 Astraea	23	12	54.30	—	8	34	47.8	+0.06 —3.8
943	Sep.	28.54264	5 Astraea	22	55	29.10	—	10	47	41.8	+0.08 —3.5
944	Apr.	28.57492	12 Victoria	14	23	22.90	—	18	55	51.6	—0.01 —2.2
945	May	2.57965	12 Victoria	14	19	33.42	—	18	17	47.7	+0.05 —2.3
946	Aug.	8.64246	14 Irene	22	12	28.43	—	23	33	39.9	+0.06 —1.7
947	Sep.	6.51843	14 Irene	21	47	09.66	—	26	01	41.2	—0.03 —1.2
948	Aug.	8.57285	22 Kalliope	20	51	45.88	—	36	36	02.8	+0.01 —0.4
949	Sep.	1.49965	22 Kalliope	20	32	37.77	—	37	11	35.9	+0.04 +0.5
950	Apr.	27.65332	33 Polyhymnia	16	01	16.08	—	22	42	15.1	+0.01 —1.7
951	May	17.59648	33 Polyhymnia	15	44	10.34	—	22	06	09.5	+0.05 —1.8
952	Aug.	11.64666	35 Leukothea	22	23	20.56	—	15	40	35.8	+0.03 —2.7
953	Sep.	20.52294	35 Leukothea	21	52	21.65	—	17	00	22.3	+0.09 —2.6
954	Aug.	30.61672	44 Nysa	23	22	29.10	—	7	33	58.2	+0.01 —3.9
955	Sep.	28.54264	44 Nysa	22	57	42.52	—	10	39	29.2	+0.08 —3.5
956	May	9.65362	48 Doris	16	26	13.80	—	13	48	31.7	+0.06 —3.0
957	June	9.52405	48 Doris	16	03	09.17	—	12	21	43.3	—0.03 —3.2
958	Aug.	9.57715	49 Pales	21	32	16.97	—	11	43	22.6	—0.05 —3.3
959	Sep.	1.52767	49 Pales	21	14	10.19	—	12	50	30.8	+0.03 —3.1
960	Mar.	29.65434	54 Alexandra	14	05	58.96	—	31	21	12.6	+0.02 —1.3



TABLE I—*continued*

No.	1960	U.T.	Planet	R.A. (1950·0)			Dec. (1950·0)			Parallax Factors
				h	m	s	°	'	"	s
961	Apr.	27·53689	54 Alexandra	13	39	07·50	—31	00	35·5	—0·05 —0·4
962	May	10·67396	90 Antiope	17	11	45·86	—22	52	01·0	+0·04 —1·7
963	July	4·49802	90 Antiope	16	30	57·27	—22	29	32·6	+0·05 —1·7
964	Mar.	30·63434	94 Aurora	13	02	11·81	— 9	09	01·3	+0·10 —3·7
965	Apr.	26·52461	94 Aurora	12	42	09·43	— 7	50	01·8	+0·03 —3·8
966	June	9·66494	96 Aegle	19	11	45·61	—39	08	57·3	+0·01 +0·8
967	July	6·56472	96 Aegle	18	44	51·52	—38	46	18·3	—0·03 +0·8
968	May	10·65180	100 Hekate	16	53	14·17	—13	51	54·4	+0·01 —3·0
969	June	16·51014	100 Hekate	16	24	47·63	—13	25	20·7	—0·06 —3·1
970	Mar.	24·67510	109 Felicitas	14	21	26·69	—19	00	43·3	+0·01 —2·2
971	Apr.	19·60895	109 Felicitas	14	00	23·51	—18	09	58·7	+0·07 —2·4
972	Apr.	19·56147	112 Iphigenia	13	08	32·07	—11	11	05·4	+0·03 —2·9
973	May	2·50882	112 Iphigenia	12	57	40·77	—10	05	06·0	0·00 —3·5
974	Sep.	6·54426	113 Amalthea	22	52	51·73	—12	42	40·2	—0·09 —3·2
975	Apr.	27·60754	118 Peitho	15	01	54·88	—16	20	40·2	0·00 —2·6
976	May	9·57294	118 Peitho	14	49	37·32	—15	59	48·0	+0·02 —2·7
977	Apr.	28·64643	146 Lucina	16	08	34·12	— 9	45	27·4	—0·02 —3·6
978	May	10·63031	146 Lucina	15	58	39·76	— 9	54	54·3	+0·06 —3·6
979	May	4·61812	158 Koronis	15	23	22·09	—19	45	24·0	+0·05 —2·1
980	July	5·57894	170 Maria	18	42	06·68	—31	16	04·7	+0·02 —0·4
981	July	20·53803	170 Maria	18	26	27·45	—30	05	40·9	+0·06 —0·6
982	Mar.	9·61381	188 Menippe	11	46	33·02	—15	17	07·3	+0·02 —2·8
983	Mar.	24·56070	188 Menippe	11	34	31·41	—13	48	25·4	+0·01 —3·0
984	June	7·59963	198 Ampella	17	10	55·81	—25	53	08·1	+0·05 —1·2
985	July	4·52118	198 Ampella	16	44	16·16	—23	12	53·7	+0·09 —1·6
986	Apr.	19·68228	216 Kleopatra	15	36	19·37	—15	19	30·5	+0·09 —2·8
987	May	9·59890	216 Kleopatra	15	21	38·90	—13	26	23·9	+0·03 —3·0
988	Apr.	28·53614	220 Stephania	13	31	17·94	—19	10	44·0	—0·02 —2·2
989	May	4·53522	220 Stephania	13	25	44·04	—18	21	46·5	+0·04 —2·3
990	July	6·62178	235 Carolina	19	47	55·94	—31	16	08·5	+0·04 —0·4
991	July	18·56047	235 Carolina	19	36	51·76	—32	11	40·8	—0·05 —0·3
992	Aug.	11·48912	235 Carolina	19	17	41·48	—33	03	07·7	—0·02 —0·1
993	Oct.	26·64849	273 Atropos	3	59	29·04	— 9	25	58·7	0·00 —3·6
994	Nov.	7·60714	273 Atropos	3	49	34·24	—11	04	28·4	—0·01 —3·4
995	May	4·69746	308 Polyxo	16	57	36·14	—16	48	49·6	+0·09 —2·6
996	June	23·53496	308 Polyxo	16	18	48·40	—14	51	12·3	+0·09 —2·9
997	June	16·59112	310 Margarita	17	17	55·08	—20	20	50·2	+0·08 —2·1
998	June	23·56880	310 Margarita	17	11	48·26	—20	08	27·8	+0·08 —2·1
999	June	9·69518	312 Pieretta	19	50	03·15	—36	01	53·8	+0·02 +0·4
1000	July	5·60722	312 Pieretta	19	30	21·91	—37	35	31·9	+0·01 +0·6
1001	Aug.	29·57819	318 Magdalena	22	10	01·78	— 8	49	54·2	+0·04 —3·7
1002	Aug.	30·57604	318 Magdalena	22	09	21·33	— 8	56	23·7	+0·04 —3·7
1003	Aug.	4·66525	328 Gudrun	22	49	40·55	—17	05	12·6	+0·01 —2·5
1004	June	16·59112	334 Chicago	17	22	35·63	—18	20	52·7	+0·07 —2·4
1005	June	23·56880	334 Chicago	17	17	48·87	—18	21	58·0	+0·07 —2·4
1006	Aug.	16·64305	340 Eduarda	22	51	37·89	—13	40	21·6	+0·04 —3·0
1007	Sep.	28·49498	340 Eduarda	22	17	41·02	—15	50	58·8	+0·02 —2·7
1008	June	7·63619	364 Isara	17	59	57·74	—19	54	24·6	+0·06 —2·1
1009	Mar.	9·70020	366 Vincentina	13	03	04·15	—13	04	09·5	0·00 —3·1
1010	Mar.	29·61840	366 Vincentina	12	48	28·24	—12	42	35·5	+0·07 —3·2
1011	May	31·60883	370 Modestia	16	55	09·30	—31	02	52·9	+0·05 —0·4
1012	June	16·54803	370 Modestia	16	37	27·34	—29	41	56·2	+0·04 —0·6
1013	Aug.	9·60003	372 Palma	21	48	15·24	—16	54	57·6	—0·02 —2·6
1014	Aug.	30·54862	372 Palma	21	28	19·34	—16	41	59·2	+0·05 —2·6
1015	Sep.	29·64012	423 Diotima	1	16	40·77	— 7	02	00·2	+0·09 —4·0
1016	Oct.	27·54615	423 Diotima	0	54	53·90	— 8	01	33·3	+0·08 —3·8
1017	Oct.	11·62278	424 Gratia	2	06	44·24	— 0	51	20·6	+0·03 —4·8
1018	Oct.	27·58015	424 Gratia	1	53	15·43	— 1	52	20·0	+0·06 —4·6
1019	July	6·59090	426 Hippo	18	54	42·74	—37	48	58·3	+0·05 +0·6
1020	July	19·58103	436 Patricia	19	43	24·28	—45	17	31·5	+0·02 +1·8
1021	Aug.	16·49256	436 Patricia	19	17	56·10	—43	24	05·7	+0·04 +1·5
1022	Apr.	28·67675	445 Edna	16	35	00·20	—44	23	15·9	+0·03 +1·6
1023	June	2·59434	445 Edna	16	02	59·64	—42	55	53·3	+0·17 +1·2

TABLE I—*continued*

No.	1960	U.T.	Planet	R.A. (1950.0)			Dec. (1950.0)			Parallax Factors	
				h	m	s	°	'	"	s	"
1024	July	20.61046	447 Valentine	20	20	43.75	-25	06	08.4	+0.04	-1.3
1025	Aug.	11.53005	447 Valentine	20	02	35.09	-26	13	52.1	+0.01	-1.1
1026	Sep.	28.62678	448 Natalie	1	03	49.87	-3	36	09.9	+0.07	-4.4
1027	Nov.	7.48903	448 Natalie	0	33	15.31	-3	02	53.7	+0.05	-4.5
1028	Sep.	29.60982	449 Hamburga	0	21	38.74	-2	52	11.2	+0.11	-4.5
1029	Oct.	27.50557	449 Hamburga	0	00	13.14	-4	45	39.2	+0.08	-4.3
1030	May	9.62710	454 Mathesis	16	26	28.08	-26	50	16.8	-0.02	-1.1
1031	June	23.48077	454 Mathesis	15	46	19.09	-26	45	08.5	-0.01	-1.1
1032	Mar.	7.64347	456 Abnoba	12	21	34.24	-20	53	33.1	+0.02	-1.9
1033	Mar.	23.57978	456 Abnoba	12	10	48.29	-19	13	04.6	-0.02	-2.2
1034	Mar.	29.57355	456 Abnoba	12	06	21.10	-18	17	16.6	+0.03	-2.3
1035	Sep.	1.61502	474 Prudentia	23	23	24.81	-4	48	07.4	+0.02	-4.3
1036	Sep.	29.54103	474 Prudentia	23	06	20.52	-9	54	56.2	+0.06	-3.6
1037	Mar.	3.61743	476 Hedwig	11	02	51.16	-10	10	53.0	+0.08	-3.5
1038	Mar.	9.57357	476 Hedwig	10	57	21.74	-9	52	09.6	0.00	-3.5
1039	Mar.	23.53527	476 Hedwig	10	45	15.64	-8	49	45.3	+0.03	-3.7
1040	Mar.	31.55812	476 Hedwig	10	39	33.72	-8	07	29.4	+0.18	-3.9
1041	Sep.	26.67709	484 Pittsburghia	1	49	58.86	-8	20	33.5	+0.11	-3.8
1042	Oct.	26.57767	484 Pittsburghia	1	26	41.89	-11	25	30.1	+0.11	-3.4
1043	July	5.64322	486 Cremona	20	09	48.54	-26	27	14.1	+0.04	-1.1
1044	July	27.60182	486 Cremona	19	47	24.41	-29	36	51.3	+0.16	-0.8
1045	Aug.	25.68934	488 Kreusa	0	05	40.58	-16	11	38.0	+0.10	-2.7
1046	Oct.	11.51625	488 Kreusa	23	34	01.56	-19	19	04.3	+0.03	-2.2
1047	Oct.	10.63407	505 Cava	2	29	24.36	-2	28	26.5	+0.01	-4.6
1048	Oct.	26.61345	505 Cava	2	16	22.61	-3	12	24.0	+0.11	-4.5
1049	Nov.	7.54829	505 Cava	2	05	36.50	-3	10	16.9	+0.03	-4.5
1050	May	31.64964	508 Princetonia	18	17	06.33	-36	16	29.2	0.00	+0.4
1051	July	4.55066	508 Princetonia	17	45	37.80	-38	01	04.7	+0.06	+0.6
1052	Apr.	27.56660	514 Armida	14	21	21.52	-18	44	49.9	-0.04	-2.3
1053	Apr.	28.57492	514 Armida	14	20	33.61	-18	40	20.1	-0.01	-2.3
1054	May	2.57965	514 Armida	14	17	24.05	-18	21	58.1	+0.05	-2.3
1055	Aug.	9.62286	545 Messalina	22	07	56.45	-15	02	46.1	+0.01	-2.8
1056	Sep.	5.50899	545 Messalina	21	44	36.05	-14	49	06.9	-0.06	-2.9
1057	Apr.	19.65565	556 Phyllis	14	56	47.92	-24	42	07.1	+0.10	-1.4
1058	May	3.58992	556 Phyllis	14	43	31.46	-23	42	20.9	+0.04	-1.5
1059	Aug.	11.56578	563 Suleika	20	45	38.03	-29	46	38.3	+0.03	-0.6
1060	Aug.	29.52743	563 Suleika	20	30	32.40	-30	48	41.8	+0.11	-0.5
1061	Apr.	26.63361	586 Thekla	15	13	34.82	-18	07	42.0	+0.05	-2.4
1062	May	31.56209	586 Thekla	14	47	20.70	-16	02	03.3	+0.18	-2.8
1063	July	20.67739	680 Genoveva	21	49	30.36	-46	18	54.9	+0.07	+1.9
1064	Aug.	4.62700	680 Genoveva	21	36	03.29	-47	31	06.0	+0.07	+2.1
1065	Aug.	16.57113	680 Genoveva	21	23	39.65	-47	31	01.8	+0.01	-2.1
1066	Aug.	25.56332	680 Genoveva	21	15	21.68	-46	55	19.5	+0.11	+1.9
1067	Aug.	11.61684	691 Lehigh	21	18	48.68	-30	56	57.2	-0.02	-0.4
1068	Aug.	30.52525	691 Lehigh	21	03	52.91	-32	19	05.7	+0.03	-0.2
1069	Mar.	23.62008	694 Ekard	12	35	31.72	-19	22	20.4	+0.06	-2.2
1070	Apr.	19.51862	694 Ekard	12	14	18.36	-15	51	25.2	+0.02	-2.7
1071	Mar.	24.63644	695 Bella	12	54	20.98	-27	53	50.5	+0.08	-0.9
1072	Apr.	26.49994	695 Bella	12	25	28.77	-24	31	44.8	-0.01	-1.4
1073	June	16.59112	700 Auravictrix	17	18	49.88	-19	56	12.0	+0.08	-2.1
1074	June	23.56880	700 Auravictrix	17	11	29.47	-20	20	47.6	+0.09	-2.1
1075	Mar.	23.66577	702 Alauda	13	15	44.57	-38	33	03.5	+0.14	+0.6
1076	Apr.	27.51050	702 Alauda	12	46	40.33	-36	36	10.4	-0.01	+0.5
1077	July	20.61046	725 Amanda	20	21	31.66	-24	39	58.9	+0.04	-1.4
1078	Sep.	28.66644	729 Watsonia	1	47	46.97	-15	36	22.9	+0.10	-2.8
1079	Nov.	10.51418	729 Watsonia	1	15	52.82	-18	16	35.1	+0.06	-2.4
1080	Apr.	28.61567	733 Mocia	15	23	03.81	-46	18	45.2	-0.08	+1.9
1081	Aug.	22.62408	739 Mandeville	23	11	46.88	-17	37	03.6	-0.01	-2.4
1082	June	16.66603	752 Sulamitis	19	18	56.52	-24	35	46.4	+0.06	-1.4
1083	July	27.53993	752 Sulamitis	18	39	50.91	-26	50	28.3	+0.10	-1.1
1084	Aug.	22.62408	782 Montefiore	23	07	22.65	-15	31	23.3	0.00	-2.7
1085	July	5.57894	785 Zwetana	18	47	41.17	-33	55	08.5	+0.01	0.0
1086	July	19.54162	785 Zwetana	18	33	19.07	-34	57	17.2	+0.05	+0.2

TABLE I—*continued*

No.	1960	U.T.	Planet	R.A. (1950.0)			Dec. (1950.0)			Parallax Factors	
				h	m	s	°	'	"	s	"
1087	July	28.50343	785 Zwetana	18	26	15.98	-35	18	01.1	+0.02	+0.2
1088	June	16.62660	786 Bredichina	18	29	56.67	-24	27	20.4	+0.04	-1.4
1089	July	19.51455	786 Bredichina	18	02	20.73	-27	24	28.4	+0.03	-1.0
1090	Apr.	26.57724	796 Sarita	14	34	06.76	-18	44	39.4	-0.05	-2.3
1091	May	17.55467	796 Sarita	14	11	57.93	-18	32	14.4	+0.12	-2.4
1092	May	31.46033	796 Sarita	13	59	51.41	-18	21	45.3	-0.04	-2.3
1093	Sep.	28.59453	809 Lundia	0	36	49.61	-4	51	29.0	+0.03	-4.2
1094	Oct.	11.55018	809 Lundia	0	27	47.98	-6	52	54.4	+0.02	-4.0
1095	Aug.	29.57819	810 Atossa	22	14	29.16	-11	05	42.7	+0.03	-3.4
1096	Aug.	30.57604	810 Atossa	22	13	41.89	-11	12	56.2	+0.03	-3.4
1097	Aug.	16.64305	825 Tanina	22	50	14.65	-12	26	09.4	+0.04	-3.2
1098	Apr.	27.60754	828 Lindemannia	15	00	32.96	-18	15	26.3	0.00	-2.3
1099	Mar.	24.67510	830 Petropolitana	14	15	29.56	-17	27	57.6	+0.02	-2.5
1100	Apr.	19.60895	830 Petropolitana	13	58	05.55	-16	25	03.6	+0.08	-2.6
1101	May	4.56962	834 Burnhamia	14	19	17.31	-10	00	26.2	+0.03	-3.5
1102	May	30.48084	834 Burnhamia	14	03	49.54	-8	20	16.1	+0.01	-3.8
1103	July	20.64650	852 Wladilena	21	45	54.38	-67	33	09.3	-0.10	+4.9
1104	Aug.	3.60989	852 Wladilena	21	24	19.51	-67	42	21.4	+0.04	+4.9
1105	Aug.	24.55323	852 Wladilena	20	53	40.63	-63	36	45.3	+0.18	-4.3
1106	July	5.67957	855 Newcombia	20	52	05.21	-39	11	35.9	+0.07	+0.8
1107	Mar.	24.59976	860 Ursina	12	23	04.95	-21	24	12.2	+0.03	-1.9
1108	Mar.	30.58996	860 Ursina	12	17	35.47	-21	07	49.2	+0.05	-1.9
1109	Mar.	7.64347	862 Franzia	12	14	18.11	-21	23	58.8	+0.04	-1.9
1110	Mar.	9.65092	862 Franzia	12	12	39.05	-21	23	57.6	+0.09	-1.9
1111	Mar.	29.57355	862 Franzia	11	54	54.38	-20	37	05.5	+0.05	-2.0
1112	Apr.	26.63361	910 Anneliese	15	19	55.26	-17	05	11.7	+0.03	-2.5
1113	May	31.56209	910 Anneliese	14	49	08.30	-17	32	18.7	+0.18	-2.6
1114	Aug.	4.66525	974 Lioba	22	42	16.78	-16	45	25.5	+0.03	-2.6
1115	Mar.	3.56286	980 Anacostia	10	27	59.25	-10	59	29.5	-0.02	-3.4
1116	Mar.	9.54124	980 Anacostia	10	22	50.32	-10	37	20.0	-0.02	-3.4
1117	Mar.	29.51495	980 Anacostia	10	08	41.82	-9	01	26.7	+0.10	-3.7
1118	July	5.57894	982 Franklina	18	36	18.03	-31	18	43.1	+0.04	-0.4
1119	July	20.53803	982 Franklina	18	23	20.22	-29	29	05.5	+0.07	-0.7
1120	Mar.	7.60377	983 Gunila	11	17	14.10	-18	25	30.8	+0.04	-2.3
1121	Mar.	30.54086	983 Gunila	11	00	58.99	-16	09	36.1	+0.07	-2.7
1122	June	16.66603	986 Amelia	19	12	02.36	-24	32	12.4	+0.07	-1.4
1123	July	27.53993	986 Amelia	18	37	52.93	-28	35	36.9	+0.11	-0.9
1124	July	5.57894	987 Wallia	18	40	48.75	-33	16	53.9	+0.03	-0.0
1125	July	19.54162	987 Wallia	18	28	04.85	-32	36	02.6	+0.06	-0.2
1126	Aug.	24.69191	1028 Lydina	0	18	10.20	-11	53	46.2	+0.07	-3.3
1127	Aug.	30.65493	1028 Lydina	0	15	09.73	-12	21	38.7	+0.02	-3.2
1128	Apr.	27.65332	1042 Amazone	15	59	15.73	-21	46	11.7	+0.02	-1.8
1129	May	17.59648	1042 Amazone	15	41	43.70	-22	36	14.9	+0.05	-1.7
1130	May	30.60077	1092 Lilium	16	47	13.07	-29	39	21.1	+0.04	-0.6
1131	June	16.54803	1092 Lilium	16	31	52.18	-28	46	00.0	+0.07	-0.8
1132	Aug.	29.65717	1107 Lictoria	0	04	49.63	-8	53	41.5	+0.04	-3.7
1133	Oct.	10.55810	1107 Lictoria	23	37	02.45	-12	19	32.0	+0.15	-3.3
1134	Aug.	25.61356	1111 Reimnuthia	22	06	45.86	-13	35	55.4	+0.12	-3.1
1135	Sep.	20.52294	1111 Reimnuthia	21	50	07.83	-15	32	32.0	+0.10	-2.8
1136	Sep.	26.67709	1115 Sabauda	1	51	52.59	-7	59	25.4	+0.11	-3.8
1137	Oct.	26.57767	1115 Sabauda	1	28	06.18	-9	19	13.9	+0.10	-3.7
1138	July	18.62760	1142 Aetolia	20	31	36.34	-17	56	51.6	+0.05	-2.4
1139	Apr.	7.65564	1197 Rhodesia	13	19	00.56	-28	01	04.0	+0.22	-1.1
1140	May	2.53878	1197 Rhodesia	13	02	25.93	-23	59	13.6	+0.09	-1.5
1141	Aug.	30.61672	1223 Neckar	23	13	25.90	-8	40	40.4	+0.03	-3.7
1142	Aug.	30.65493	1237 Genevieve	0	24	18.78	-13	35	23.5	0.00	-3.0
1143	Sep.	20.62273	1237 Genevieve	0	07	12.75	-15	10	03.2	+0.11	-2.8
1144	Aug.	29.61692	1310 Villigera	22	48	13.55	-22	59	30.5	+0.08	-1.7
1145	Sep.	20.56872	1310 Villigera	22	17	41.78	-22	00	49.1	+0.19	-2.0
1146	Apr.	27.56660	1319 Disa	14	20	15.01	-17	12	38.5	-0.04	-2.5
1147	Apr.	28.57492	1319 Disa	14	19	28.04	-17	07	34.2	0.00	-2.5
1148	Aug.	25.65392	1390 Abastumani	23	29	21.23	-27	49	04.3	+0.07	-0.9
1149	Aug.	25.61356	Unidentified	22	14	15.14	-16	04	37.9	+0.11	-2.8

TABLE II

No.	Comparison Stars	Dependences			
941	Yale 16 8277, 8297, 8300	0·30557	0·29974	0·39469	R
942	Yale 16 8249, 8255, 8271	0·54208	0·09766	0·36026	S
943	Yale 11 8060, 8064, 8083	0·40331	0·44753	0·14916	S
944	Yale 12 II 6019, 6031, 6038	0·44346	0·26844	0·28810	R
945	Yale 12 I 5324, 5357, 12 II 5994	0·10147	0·46854	0·43000	S
946	Yale 14 15140, 15151, 15163	0·38978	0·34074	0·26948	R
947	Yale 14 14924, 14954, 14964	0·43081	0·25672	0·31247	S
948	Cape 18 10801, 10807, 10833	0·26066	0·41688	0·32246	R
949	Cape 18 10662, 10663, 10689	0·27661	0·40247	0·32091	R
950	Yale 14 11266, 11292, 11313	0·23663	0·42431	0·33906	R
951	Yale 13 I 6506, 6520, 14 11139	0·16384	0·32648	0·50968	R
952	Yale 12 I 8359, 8382, 8383	0·50815	0·24989	0·24196	R
953	Yale 12 I 8200, 8239 12 II 9343	0·41920	0·34413	0·23668	R
954	Yale 16 8300, 8314, 8316	0·26488	0·18323	0·55189	R
955	Yale 11 8060, 8064, 8083	0·20157	0·22859	0·56984	S
956	Yale 11 5695, 5712, 12 I 5953	0·34357	0·23177	0·42466	W
957	Yale 11 5563, 5570, 5584	0·10520	0·59044	0·30436	R
958	Yale 11 7645, 7649, 7660	0·35589	0·34959	0·29453	R
959	Yale 11 7530, 7532, 7550	0·30108	0·21297	0·48595	R
960	Cape 17 7207, 7231, 7249	0·28652	0·60923	0·10425	W
961	Cape 17 6939, 6944, 6978	0·45732	0·37698	0·16570	R
962	Yale 14 11903, 11909, 11936	0·37720	0·42580	0·19700	W
963	Yale 14 11498, 11512, 11535	0·30787	0·39726	0·29486	S
964	Yale 16 4701, 4714, 4717	0·34811	0·32242	0·32947	W
965	Yale 16 4625, 4630, 4642	0·28181	0·52126	0·19693	R
966	Cape 18 9966, 9985, 9993	0·22967	0·29821	0·47212	R
967	Cape 18 9699, 9716, 9746	0·35172	0·37346	0·27482	S
968	Yale 12 I 6048, 6065, 11 5808	0·43241	0·21020	0·35739	W
969	Yale 11 5692, 5698, 5699	0·39914	0·41548	0·18538	S
970	Yale 12 II 5995, 6016, 6031	0·23432	0·45063	0·31505	S
971	Yale 12 I 5244, 5252, 5270	0·32390	0·41113	0·26497	W
972	Yale 11 4712, 4718, 4727	0·25940	0·43865	0·30194	W
973	Yale 16 4682, 4690, 4700	0·13277	0·54436	0·32287	S
974	Yale 11 8049, 8052, 8066	0·41183	0·30778	0·28038	S
975	Yale 12 I 5550, 5562, 5565	0·60323	0·33098	0·06579	R
976	Yale 12 I 5471, 5496, 5504	0·39086	0·24639	0·36275	W
977	Yale 16 5622, 5624, 5631	0·25478	0·40311	0·34210	R
978	Yale 16 5564, 5582, 11 5557	0·58204	0·25883	0·15913	W
979	Yale 12 II 6369, 6381, 6389	0·40948	0·16813	0·42239	S
980	Cape 17 10149, 10165, 10177	0·70337	—0·49388	0·79051	S
981	Yale 13 II 11966, 11997, Cape 17 10013	0·39175	0·25806	0·35019	R
982	Yale 12 I 4597, 4608, 4627	0·17252	0·49282	0·33466	W
983	Yale 11 4316, 4325, 4333	0·51703	0·31537	0·16760	S
984	Yale 14 11892, 11894, 11921	0·34545	0·35841	0·29614	R
985	Yale 14 11589, 11607, 11628	0·25880	0·44408	0·29712	S
986	Yale 12 I 5723, 5728, 5743	0·34683	0·35806	0·29511	W
987	Yale 11 5370, 5378, 5387	0·28812	0·20484	0·50703	W
988	Yale 12 II 5750, 5766, 5784	0·49472	0·23676	0·26852	R
989	Yale 12 II 5731, 5743, 12 I 5093	0·25445	0·29915	0·44640	S
990	Cape 17 10801, 10809, 10823	0·11657	0·59757	0·28586	S
991	Cape 17 10690, 10718, 10727	0·18510	0·44418	0·37072	R
992	Cape C7 10526, 10551, 10574	0·24090	0·56287	0·19623	R
993	Yale 16 975, 977, 999	0·38819	0·40315	0·20867	S
994	Yale 11 888, 891, 907	0·55866	0·04773	0·39361	W
995	Yale 12 I 6066, 6079, 6095	0·16890	0·67134	0·15976	S
996	Yale 12 I 5920, 5923, 5933	0·17024	0·42178	0·40799	W
997	Yale 13 I 7077, 7107, 7118	0·48147	0·32418	0·19434	S
998	Yale 13 I 7034, 7066, 12 II 7047	0·34537	0·13861	0·51602	W
999	Cape 18 10275, 10287, 10307	0·30829	0·20756	0·48415	R
1000	Cape 18 10114, 10139, 10164	0·28655	0·44992	0·26352	S
1001	Yale 16 7954, 7960, 7961	0·38005	0·25904	0·36091	R
1002	Yale 16 7948, 7954, 7971	0·09306	0·74807	0·15887	R
1003	Yale 12 I 8470, 8486, 8491	0·09131	0·64656	0·26213	W
1004	Yale 12 II 7126, 7135, 7154	0·36966	0·36163	0·26870	S
1005	Yale 12 II 7080, 7087, 7117	0·37363	0·31298	0·31339	W

TABLE II—*continued*

No.	Comparison Stars	Dependences			
1006	Yale 12 I 8490, 8502, 8513	0·49800	0·31780	0·18420	S
1007	Yale 12 I 8333, 8342, 8358	0·38056	0·36838	0·25106	S
1008	Yale 12 II 7411, 7433, 13 I 7421	0·36914	0·25950	0·37136	R
1009	Yale 11 4682, 4698, 4701	0·39741	0·29194	0·31065	W
1010	Yale 11 4619, 4625, 4636	0·15210	0·47340	0·37450	W
1011	Cape 17 8889, 8906, 8922	0·41656	0·42239	0·16105	W
1012	Yale 13 II 10406, 10435, 10448	0·22236	0·39443	0·38321	S
1013	Yale 12 I 8193, 8195, 8199	0·27921	0·40455	0·31624	R
1014	Yale 12 I 8083, 8090, 8106	0·27879	0·37852	0·34269	R
1015	Yale 16 254, 273, 275	0·41602	0·10697	0·47701	S
1016	Yale 16 187, 191, 199	0·18904	0·29832	0·51264	S
1017	Yale 21 429, 436, 438	0·24416	0·57127	0·18457	R
1018	Yale 17 439, 440, 448	0·49166	0·10785	0·40050	S
1019	Cape 18 9791, 9816, 9827	0·24951	0·48916	0·26133	S
1020	Cord. D 14445, 14468, 14472	0·33457	0·29255	0·37288	R
1021	Cord. D 14182, 14210, 14233	0·38159	0·23986	0·37855	S
1022	Cord. D 11574, 11597, 11634	0·14403	0·54203	0·31394	R
1023	Cord. D 11207, 11252, 11266	0·37315	0·36846	0·25840	W
1024	Yale 14 14137, 14173, 14175	0·64921	0·16820	0·18260	R
1025	Yale 14 13960, 13987, 13989	0·26837	0·46595	0·26568	R
1026	Yale 17 232, 250, 254	0·36920	0·20389	0·42691	S
1027	Yale 17 119, 126, 134	0·60957	0·15666	0·15277	S
1028	Yale 17 72, 85, 88	0·29579	0·38649	0·31772	S
1029	Yale 17 8191, 8199, 8203	0·28845	0·57035	0·14120	S
1030	Yale 14 11477, 11496, 11499	0·25000	0·35550	0·39450	W
1031	Yale 14 11140, 11147, 11164	0·23680	0·43502	0·32818	R
1032	Yale 13 I 5367, 5383, 5386	0·31014	0·42834	0·26152	W
1033	Yale 12 II 5296, 5309, 5321	0·33112	0·54499	0·12390	S
1034	Yale 12 I 4696, 12 II 5274, 5296	0·37234	0·35770	0·26996	W
1035	Yale 17 8041, 8053, 8063	0·31822	0·27296	0·40881	R
1036	Yale 11 8101, 8117, 8121	0·37502	0·28247	0·34251	S
1037	Yale 16 4181, 4185, 4199	0·31366	0·45490	0·23144	S
1038	Yale 16 4147, 4166, 4171	0·24175	0·43299	0·32527	W
1039	Yale 16 4087, 4090, 4098	0·44738	0·29731	0·25530	S
1040	Yale 16 4056, 4059, 4073	0·20963	0·48882	0·30156	W
1041	Yale 16 373, 394, 396	0·36738	0·20493	0·42769	S
1042	Yale 11 302, 315, 322	0·17620	0·38684	0·43695	S
1043	Yale 14 14034, 14046, 14053	0·44810	0·31095	0·24095	S
1044	Yale 13 II 12988, 13010, 13055	0·41582	0·19837	0·38581	S
1045	Yale 13 I 6, 10, 19	0·35077	0·13000	0·51922	W
1046	Yale 12 II 9851, 9854, 9878	0·39698	0·09328	0·50974	R
1047	Yale 17 603, 613, 615	0·31087	0·27218	0·41695	R
1048	Yale 17 553, 559, 572	0·55679	0·21847	0·22473	S
1049	Yale 17 496, 506, 513	0·23835	0·44689	0·31476	W
1050	Cape 18 9378, 9396, 9408	0·30623	0·35387	0·33990	W
1051	Cape 18 8958, 8960, 9032	0·50304	0·14419	0·35277	S
1052	Yale 12 II 5995, 6019, 6031	0·36216	0·30557	0·33226	R
1053	Yale 12 II 5995, 6019, 6031	0·56268	0·16034	0·27698	R
1054	Yale 12 I 5324, 5357, 12 II 5994	0·43246	0·20333	0·36420	S
1055	Yale 12 I 8286, 8299, 8301	0·47897	0·17607	0·34496	R
1056	Yale 12 I 8178, 8188, 8189	0·51489	0·23195	0·25316	S
1057	Yale 14 10725, 10742, 10749	0·33750	0·30552	0·35699	W
1058	Yale 14 10605, 10622, 10623	0·48742	0·32671	0·18586	S
1059	Yale 13 II 13685, 13702, 13709	0·46521	0·27705	0·25774	R
1060	Cape 17 11205, 11209, 11216	0·30025	0·22514	0·47461	R
1061	Yale 12 I 5603, 5605, 5626	0·43564	0·10891	0·45545	R
1062	Yale 12 I 5465, 5468, 5497	0·24050	0·65972	0·09977	W
1063	Cord. D 15573, 15624, 15682	0·38481	0·28427	0·33092	R
1064	Cape Ft. 19552, 19592, 19595	0·31214	0·19850	0·48936	W
1065	Cape Ft. 19490, 19494, 19530	0·47079	0·18896	0·34025	S
1066	Cape Ft. 19438, 19447, 19468	0·25721	0·47572	0·26707	W
1067	Cape 17 11638, 11664, 11690	0·35113	0·43201	0·21686	R
1068	Cape 17 11509, 11530, 11553	0·37668	0·39424	0·22908	R
1069	Yale 12 II 5453, 5456, 5470	0·16926	0·39882	0·43193	S
1070	Yale 12 I 4728, 4737, 4746	0·39875	0·31483	0·28642	W

TABLE II—*continued*

No.	Comparison Stars	Dependences			
1071	Yale 13 II 8268, 8274, 8291	0·19880	0·29698	0·50422	S
1072	Yale 14 9384, 9389, 9414	0·22211	0·38862	0·38927	R
1073	Yale 12 II 7077, 7112, 7118	0·28823	0·21314	0·49863	S
1074	Yale 13 I 7034, 7066, 12 II 7047	0·60285	0·17018	0·22698	W
1075	Cape 18 6355, 6357, 6405	0·21671	0·42082	0·36247	S
1076	Cape 18 6074, 6075, 6096	0·44275	0·34660	0·21065	R
1077	Yale 14 14137, 14148, 14175	0·17018	0·43150	0·39832	R
1078	Yale 12 I 453, 454, 466	0·24840	0·40094	0·35065	S
1079	Yale 12 II 335, 336, 348	0·47506	0·34138	0·18357	W
1080	Cord. D 10604, 10639, 10729	0·31550	0·39662	0·28789	R
1081	Yale 12 I 8590, 8591, 8611	0·72546	0·00169	0·27285	W
1082	Yale 14 13451, 13470, 13494	0·25443	0·34266	0·40292	S
1083	Yale 13 II 12150, 14 12982, 13022	0·33485	0·44454	0·22061	S
1084	Yale 12 I 8560, 8576, 8588	0·37351	0·30204	0·32445	W
1085	Cape 17 10210, 10214, 10241	0·52485	0·22279	0·25236	S
1086	Cape 17 10047, 10070, 18 9595	0·40237	0·29440	0·30323	R
1087	Cape 18 9481, 9501, 9535	0·32700	0·35387	0·31913	S
1088	Yale 14 12844, 12845, 12905	0·52897	0·23031	0·24072	S
1089	Yale 13 II 11613, 11651, 11670	0·32653	0·38087	0·29260	R
1090	Yale 12 II 6075, 6098, 12 I 5411	0·30102	0·29084	0·40815	R
1091	Yale 12 I 5302, 5312, 12 II 5979	0·27467	0·44878	0·27655	R
1092	Yale 12 I 5242, 5255, 5281	0·64502	0·11902	0·23596	R
1093	Yale 17 127, 135, 142	0·36114	0·33482	0·30404	S
1094	Yale 16 89, 92, 96	0·40738	0·39970	0·19293	R
1095	Yale 11 7860, 7867, 7883	—0·58105	1·72870	—0·14765	R
1096	Yale 11 7858, 7867, 7871	0·27043	0·40265	0·32692	R
1097	Yale 11 8039, 8041, 8049	0·40858	0·12047	0·47095	S
1098	Yale 12 I 5535, 5544, 5558	0·28084	0·15573	0·56344	R
1099	Yale 12 I 5310, 5324, 5340	0·25794	0·19081	0·55125	S
1100	Yale 12 I 5232, 5243, 5249	0·15152	0·64056	0·20792	W
1101	Yale 16 5066, 5080, 5087	0·23364	0·24618	0·52018	S
1102	Yale 16 5000, 5010, 5013	0·43353	0·49187	0·07461	S
1103	LPID 4191, 4219, 4220	0·24560	0·43522	0·31918	R
1104	LPID 4174, 4180, 4191	0·42238	0·49834	0·07928	W
1105	Cape 20 II 6235, 6266, 6271	0·36685	0·18963	0·44352	W
1106	Cape 18 10788, 10800, 10835	0·21246	0·24210	0·54544	S
1107	Yale 13 I 5379, 5387, 5404	0·41663	0·30806	0·27531	S
1108	Yale 13 I 5331, 5350, 5367	0·34851	0·23241	0·41908	W
1109	Yale 13 I 5315, 5323, 5341	0·28190	0·28924	0·42886	W
1110	Yale 13 I 5307, 5323, 5331	0·41146	0·38259	0·20595	W
1111	Yale 12 II 5183, 5212, 13 I 5206	0·19673	0·27545	0·52782	W
1112	Yale 12 I 5631, 5639, 5653	0·20165	0·35325	0·44510	R
1113	Yale 12 I 5458, 5489, 5505	0·25834	0·45156	0·29010	W
1114	Yale 12 I 8440, 8445, 8470	0·25000	0·57066	0·17934	W
1115	Yale 11 3971, 3983, 3991	0·13038	0·57307	0·29655	S
1116	Yale 11 3958, 3980, 16 3988	0·51240	0·20877	0·27883	W
1117	Yale 16 3909, 3922, 3928	0·31484	0·31630	0·36886	W
1118	Cape 17 10088, 10090, 10105	0·21378	0·21405	0·57217	S
1119	Yale 13 II 11920, 11966, 11970	0·27407	0·22150	0·50443	R
1120	Yale 12 I 4452, 4458, 4471	0·19571	0·39349	0·41079	W
1121	Yale 12 I 4376, 4384, 4390	0·39109	0·35793	0·25097	W
1122	Yale 14 13365, 13367, 13413	0·27049	0·29910	0·43041	S
1123	Yale 13 II 12107, 12145, 12153	0·29218	0·26236	0·44545	S
1124	Cape 17 10122, 10150, 10154	0·17237	0·41613	0·41150	S
1125	Cape 17 9983, 10015, 10031	0·49274	0·23269	0·27458	R
1126	Yale 11 47, 50, 65	0·25502	0·32141	0·42357	W
1127	Yale 11 32, 45, 58	0·62874	—0·11780	0·48906	R
1128	Yale 13 I 6606, 6608, 6628	0·24903	0·27617	0·47479	R
1129	Yale 13 I 6506, 14 11112, 11139	0·54274	0·37106	0·08620	R
1130	Yale 13 II 10536, 10557, 10576	0·16637	0·66860	0·16504	W
1131	Yale 13 II 10339, 10371, 10403	0·34486	0·31771	0·33743	S
1132	Yale 16 8465, 7, 19	0·32826	0·35891	0·31283	R
1133	Yale 11 8239, 8241, 8249	0·26160	0·55979	0·17861	R
1134	Yale 12 I 8280, 8288, 8290	0·14350	0·33020	0·52629	W
1135	Yale 12 I 8196, 8200, 8216	0·48457	0·18785	0·32758	R

TABLE II—*continued*

No.	Comparison Stars	Dependences			
1136	Yale 16 373, 394, 396	0·06482	0·49255	0·44264	S
1137	Yale 16 297, 308, 11 333	0·27737	0·26723	0·45540	S
1138	Yale 12 II 8813, 8833, 12 I 7737	0·33796	0·16276	0·49927	R
1139	Yale 13 II 8456, 8492, 8506	0·40268	0·27159	0·32574	R
1140	Yale 14 9719, 9743, 9747	0·40238	0·33846	0·25916	S
1141	Yale 16 8245, 8252, 8271	0·31644	0·12825	0·55531	R
1142	Yale 12 I 117, 11 77, 82	0·50617	0·38854	0·10528	R
1143	Yale 11 15, 23, 25	0·19610	0·47880	0·32510	R
1144	Yale 14 15390, 15407, 15417	0·44051	0·13647	0·42302	R
1145	Yale 14 15169, 15173, 15208	0·44077	0·19239	0·36684	R
1146	Yale 12 I 5345, 5346, 5363	0·44660	0·27061	0·28279	R
1147	Yale 12 I 5341, 5345, 5351	0·17182	0·26641	0·56176	R
1148	Yale 13 II 13946, 13964, 13972	0·23969	0·42114	0·33917	W
1149	Yale 12 I 8318, 8325, 8331	0·40354	0·16627	0·43019	W

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Notes on Permian Sediments in the Mudgee District, N.S.W.

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Introduction

Large areas of Permian and Mesozoic rocks have long been known to occur some fifteen miles to the north-east of Mudgee (Jones, 1925 ; Dulhunty, 1940), along the western margin of coal measures and other sedimentary rocks of the Sydney and Oxley Basins.

The Mudgee district itself is generally regarded as an area occupied essentially by the outcrop of metamorphic basement rocks. However, as early as 1886 Wilkinson referred to Permian conglomerates resting on basement rocks in the Cudgegong valley near Mudgee. Again in 1936 Jones reported the exposure of basal Permian beds in the valley of McDonald's Creek near Mudgee.

More detailed investigations by the present authors have revealed several additional isolated occurrences of Permian sediments in the Mudgee district, and studies of their particular nature and mode of occurrence have thrown some light on problems of Permian palaeogeography, as outlined in this paper.

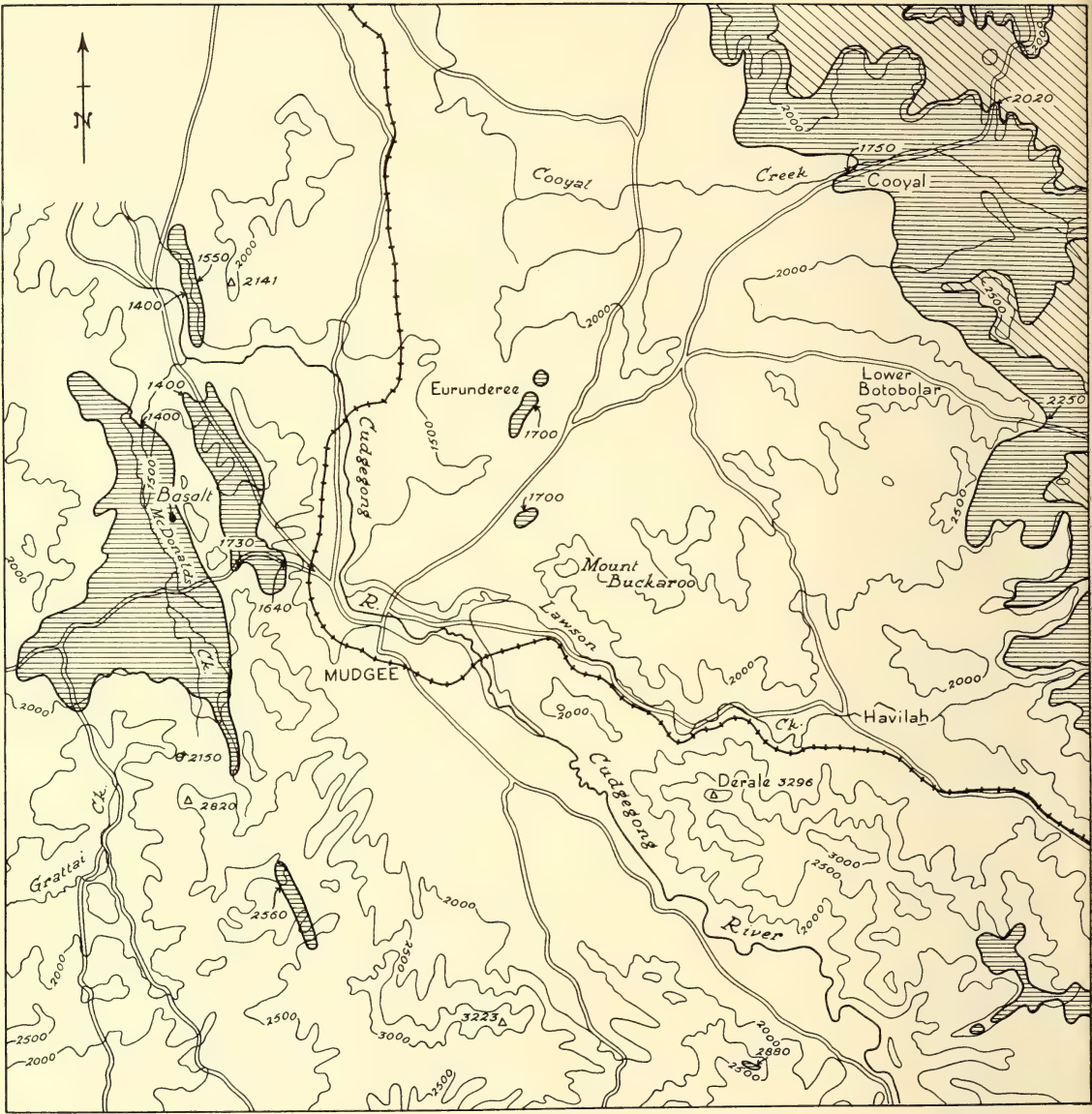
Nature and Occurrence of Permian Sediments

The main deposit is in the valley of McDonald's Creek, to the west of Mudgee (Fig. 1). It lies in the flat valley floor of the creek, to the west of an imposing ridge of Silurian subgreywackes of the Chesleigh Formation (Packham, 1961), a formation which extends continuously northwards from Sofala. The eastern side of the ridge is bounded by the northern continuation of the Wiagdon Thrust which marks the eastern edge of the Silurian-Devonian sequence of the Hill End Trough; the last movement on this fault is evidently pre-Permian.

The McDonald's Creek Permian sediments include a variety of rock types ranging from siltstones to breccias. The sediments occupy a depression above which the older Palaeozoic rocks rise to the east, south and west. To the east the ridge of the Chesleigh Formation is perforated in three places by narrow gaps through which the Permian sediments were

almost certainly connected to those lying to the east of the Chesleigh Formation. Solid outcrops of the Permian are not abundant in McDonald's Creek. No exposure is known where more than a few feet of these Permian sediments can be seen at a time. The total thickness is thus unknown, but at least 160 feet of these rocks are present at one locality. This is in the valley of McDonald's Creek just west of the ridge of the Chesleigh Formation and east of the stream about a mile north of the Mudgee-Hargraves Road. The deposit is capped with one hundred feet of basalt. Outcrops on this isolated hill are not good but it appears as if the succession is made up of interbedded sandstones and conglomerates.

The siltstones are pale greyish brown in colour and contain plant remains, largely the leaves of *Gangamopteris* sp. and indefinite plant stems. Two localities for these fossils are 150 yards downstream on McDonald's Creek, from where the Mudgee-Piambong Road crosses it and at the junction of the Hargraves and Yarrabin Roads. The sandstones in the sequence are well sorted, containing abundant rock fragments, and where they are fresh in the floor of the valley towards the north of the outcrop they have a carbonate cement. Conglomerates in the same locality consist of well-rounded pebbles in a lithic sandstone matrix (Plate I B). The conglomerates on the sides of the valley are much coarser with blocks up to a foot or so in diameter. Sometimes these blocks are sub-angular. The lithologies of the rocks in these conglomerates can be matched in the Silurian and Devonian geosynclinal rocks on the surrounding hills. Large areas of pebbles and boulders derived from the conglomerates give a false impression of the proportion of conglomerate in the Permian sequence. On the old Grattai Road one mile south of where it turns off the Mudgee-Hargraves Road a one-foot band of limestone outcrops; this rock, apparently a chemical deposit, has well developed cone-in-cone structure. This lithology has not been found in any other locality in the area.



PERMIAN SEDIMENTS OF THE MUDGEE DISTRICT

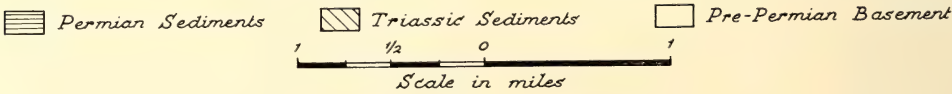


FIG. 1

A marked irregularity in the base of the Permian deposits has been found in the north-flowing head of McDonald's Creek along which a long arm of the Permian sediments extends south from the main mass of the deposit. The valley is narrow and V-shaped with Permian sediments in the base, while the hills of older Palaeozoic rocks rise sharply above it on both sides; it is clear that this is a re-excavated valley which was formed in Permian times. The sediments in the floor of this stream are different from those seen elsewhere in outcrop in the McDonald's Creek area. The rock is extremely poorly sorted; the matrix is a fine sand with angular fragments up to six inches or so scattered through it. This rock is figured in Plate I, D.

On the eastern side of the ridge of the Chesleigh Formation there is another strip of Permian sediments similar in general character to those in McDonald's Creek. This outcrop extends from just north of the Cudgegong River near where the Mudgee-Gulgong Road crosses it southwards almost to Mudgee. At the south-western end of this outcrop, in the westernmost road-cutting containing Permian sediments to the east of the Chesleigh Formation, an occurrence of varved shale has been found. Specimens of these are figured in Plate I, E and F. The thickness of the varve units is varied, as can be seen in the figures. They are pale brown and pinkish-brown in colour and, like all the sediments in this Permian outcrop, very weathered. Unfortunately the outcrop in the road cutting is not sufficiently fresh to get any idea of the thickness of the varves. Siltstones of similar colour but lacking varve structure occur on the same road about half a mile to the east. About a mile to the north large blocks, probably of erratic origin, occur in fields near the road.

Two other outcrops of Permian sediments occur at low level, to the east of Mudgee in the vicinity of Buckaroo. The outcrop of Permian west of the Cudgegong River on the southern boundary of the map is almost entirely massive sandstone differing in lithology from the rocks in the north. It can be seen that this outcrop, too, is considerably lower than the highest points on the ridge of the Chesleigh Formation lying to the west. Likewise the ridge to the east is higher than the Permian sediments. This ridge, which trends parallel to the Chesleigh Formation, is composed of another hard material—Upper Devonian quartzites and slates. This formation and the consequential ridge come to an end just north of Mount Buckaroo.

From the present distribution of Permian sediments there is little doubt that at the time of deposition of the basal Permian beds in the area this Upper Devonian ridge stood up as a high feature, as did the Chesleigh Formation. These two formations dominate the landscape in a similar fashion to-day. A minor basement rise is apparent on the map just south of Botobolar, otherwise the base of the Permian in the north-eastern part of the map seems to be nearly planar.

The Permian sediments occupying the north-east portion of the map are continuous with those of the Sydney and Oxley Basins. They outcrop from Botobolar through Cooyal to Ulan, dipping and thickening to the north-east. As indicated in the sections in Fig. 2, they appear to have extended over much of the low-lying country between Cooyal and Mudgee. Before removal from this area by relatively recent erosion, the upper portion at least of the Permian appears to have been continuous with deposits in the Mudgee-McDonald's Creek area. This, and the almost certain continuity of Permian deposits to the north-west of Mudgee along the Cudgegong valley to Guntawang and beyond, indicate a large island of basement rock standing off-shore in the Ulan-Cook's Gap-Home Rule area at the time of the deposition of the basal Permian. It would appear that this island, which consisted largely of granite, was not as high as others near by, and that the first Triassic sands overlapped the Permian around its shores, and then spread over its surface, while the Upper Devonian quartzite and Chesleigh Formation near Mudgee remained as islands in the early Triassic lakes.

Evidences of Glaciation

The existence of a Permian glaciation in New South Wales has been firmly established for some time. Erratics are common in the marine sediments and glaciated pebbles are known from Tallong (David, 1950) and Dunedoo (Kenny, 1928). However, additional evidence found recently in the Mudgee district is new and amongst the best yet recorded. Superb soled and scratched boulders occur in basal Permian deposits about one mile south-west of the Guntawang Bridge over the Cudgegong River. This is just beyond the north-west corner of the map in this paper. Some of these boulders are figured in Plate I, A and C. In addition there are varved sediments occurring three miles north-west of Mudgee on the Hargraves Road. So far as the present authors are aware, these are the only Permian varves

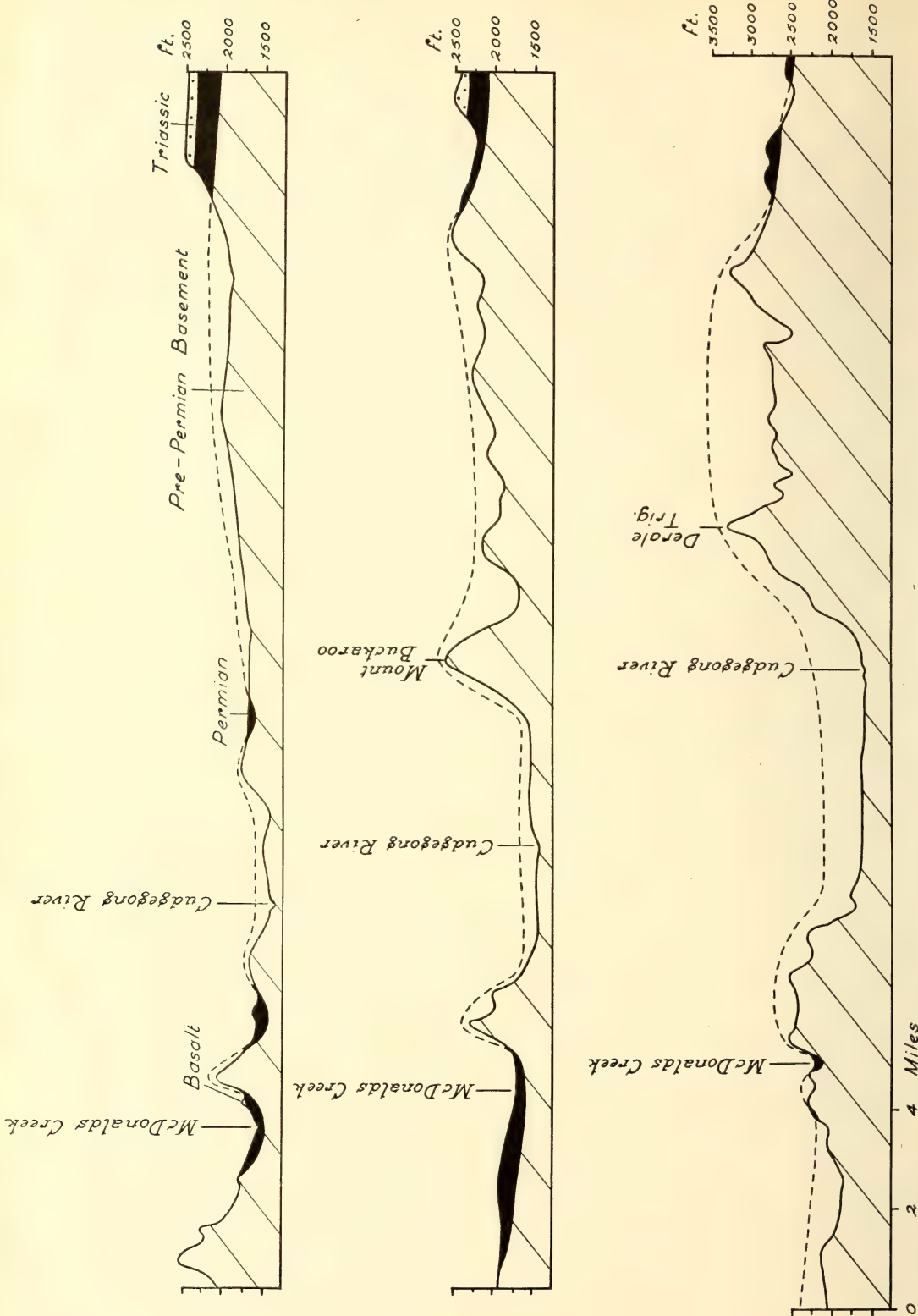
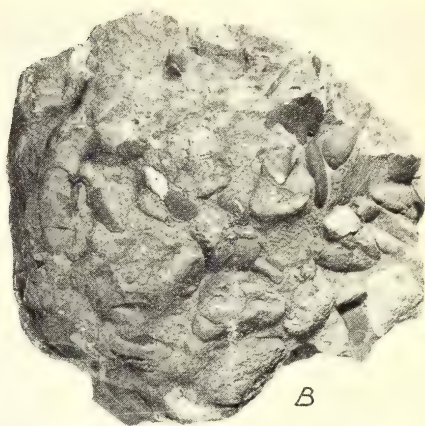


FIG. 2
Geological sections showing occurrences of Permian deposits (black) in the Mudjee district.

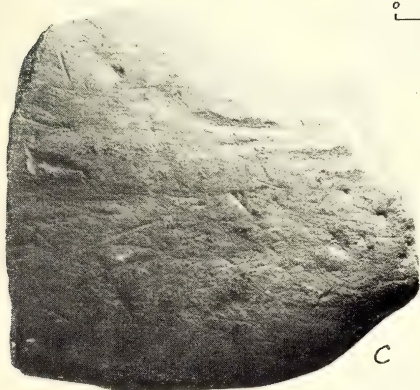


A

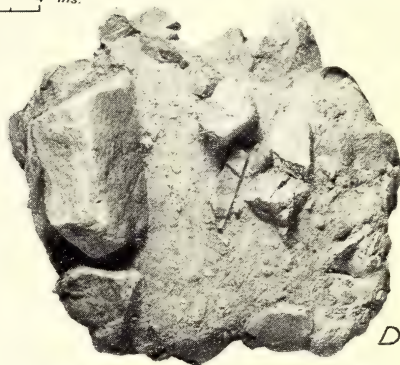


B

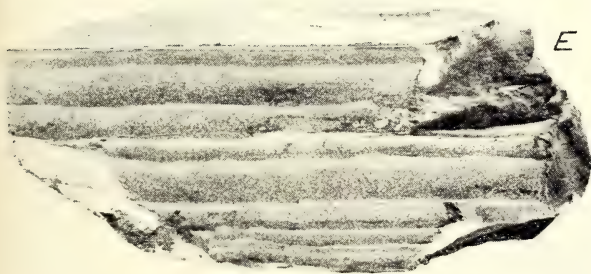
0 1 2 3 4 ins.



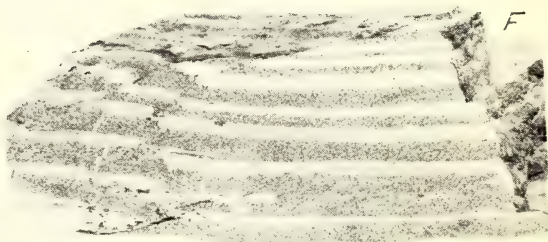
C



D



E



F

0 1 2 3 ins.

Explanation

Specimens from Permian sediments near Mudgee, N.S.W., showing evidence of glaciation. For descriptions and localities see text.

which have been recorded in eastern Australia, but undoubtedly more remain to be discovered in the Mudgee district and other areas of Permian shoreline deposition. It is understood that E. C. Andrews collected shales which he believed looked like varves in the vicinity of Wallerawang.

The glaciation was apparently not extremely intense since the valley-fill sediments are essentially non-glacial. It also seems unlikely that the valleys had been filled with glacial sediment and reworked, since no sign of residual tillite has been found. The presence of varves indicates that there was a general freeze during winter. The presence of the coarsest boulder deposits on the sides of the valleys may be explained by the existence of cirque glaciers on the ridges above. The scratched boulders figured were found in this type of location and evidently they were not re-transported by water. Wherever the boulder beds were examined carefully it was found that the rock types present outcrop in the basement within a couple of miles of the locality. Thus, so far, there is no evidence of long-distance transportation by ice.

Correlation of the Permian Sediments

The Permian sediments of the McDonald's Creek area and those to the north of Mudgee can be correlated with either the marine Capertee Group or the overlying Lithgow Coal Measures. The presence of erratic blocks and fluvio-glacial sediments in the Capertee Group, and the absence of evidence of glaciation from the Lithgow Coal Measures, suggests that the deposits mentioned above should be correlated with the Capertee Group. There is no direct evidence that any of the Permian sediments in the Mudgee district are marine. Their location in narrow valleys and the presence of beds of plant fossils, in silts similar to those found in the coal measures, suggests that they are fresh-water deposits.

One interesting point which might be mentioned is that the only leaf impressions found after a good deal of searching were those of *Gangamopteris* sp., whereas *Glossopteris* spp. are the dominant fossils in the coal measures to the east. This evidence strongly suggests ecological control of the flora since, on the whole, it has not been possible to differentiate a floral succession in the Permian of New South Wales.

The small outcrop of sandstone lying to the west of the Cudgegong River near the southern margin of the map is lithologically similar to

the rocks of the coal measures, suggesting that the Capertee Group is here overlapped by the Lithgow Coal Measures. Similar overlaps have been observed on the margin of the main outcrop of the Permian to the east.

Structure and Geomorphology

The base of the Permian in the area covered by the map dips gently to the north. Along the eastern margin there is a distinct easterly component where the sediments dip down gently into the Permo-Triassic Basin. On the western side there is a general westerly component into the Great Artesian Basin. The valley deposits of Permian near Mudgee occur generally at about 1,500 feet above sea-level, whilst elevated outliers of similar sediments, situated on a more planar basement surface, occur at about 3,200 feet, some 16 miles to the south-east between Upper Meroo and Mt. Bocoble.

It is believed that the present high-level Permian between Mt. Bocoble and Upper Meroo was deposited at approximately the same time as the present low-level Permian deposits of the McDonald's Creek and others near Mudgee along shorelines of the same sea-level. However, subsequent uplifting, possibly in the early Tertiary, elevated the country to the east and south-east of Mudgee, including the Mt. Bocoble-Upper Meroo area. This produced an upwarped surface rising to a broad anticlinal structure immediately to the east of Mudgee. Drainage to the west, initiating the early history of the present Cudgegong River, produced a mature elevated Miocene surface on which older Palaeozoic rocks outcropped where erosion had penetrated the Permian sediments. Post-Miocene uplifting of the Kosciusko Epoch then elevated the country between much wider limits than the earlier uplift, and the present topographical situation was subsequently produced by erosion, leaving the high-level outliers of Permian to the east, and the low-level valley deposits around Mudgee.

The thickness of the Permian on the eastern edge of the map is approximately 260 feet (in the vicinity of Cooyal) and it seems improbable that it would have been substantially thicker in the vicinity of Mudgee. It also seems improbable that the high ridges of older Palaeozoic rocks would have survived erosion if they had been exposed since the end of the Palaeozoic Era. In the cross-sections a hypothetical surface is shown representing the profile of the older Palaeozoic rocks at the time of deposition of the basal Permian beds. The

older rocks rise some 1,500 feet above the base of the Permian at present, and possibly 3,000 feet at the time of deposition of the Permian. In view of this, it seems highly probable that Permian coal measures, Triassic and even Jurassic sediments may have been deposited over the equivalents of the marine Capertee Group near Mudgee, filling up the valleys and producing a level surface of Mesozoic sediments. Beneath this cover Permian basement topography remained buried and protected from denudation. Tertiary uplifts and Pleistocene erosion have re-excavated and revealed the old surfaces. Now, some of our present-day streams flow through Permian valleys, possibly sculptured by glaciers, in which

were embedded the morainic materials found to-day in the boulders and erratics of the basal Permian beds.

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Further Notes on Assemblages of Graptolites in New South Wales

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ABSTRACT—The paper commences with a summary of the characteristic graptolitic succession (or graptolite zones) so far recognised in New South Wales. Evidence is given that the graptolites of several of these zones are known to occur in slates with a remarkably high silica percentage. Since a considerable period of time must have elapsed between the first and the last zone, the high silica percentage of the slates cannot be due to a single outpouring of volcanic ash.

Several graptolites, including a new variety, are described. The significance of an appendage on a *Climacograptus* is discussed. New collections are allotted to graptolite zones and in two cases arranged in tabular form. In the light of collections which have become available for description since my previous paper (Sherrard, 1954), adjustments have been made to some of the previous allotments to graptolite zones. In some cases the new graptolite discoveries are from rocks whose age was unknown before. Illustrations are by photograph or by camera lucida drawing where preservation did not permit photographing.

Introduction and Acknowledgements

Since the publication of "The Assemblages of Graptolites in New South Wales" (Sherrard, 1954) I have had the opportunity of examining further collections of graptolites made by officers of the Geological Survey and other workers. In a number of cases these collections are from new localities for these fossils, while in others, larger collections enabling precise zoning have been made from localities from which only a few specimens had previously been known.

In the succession of assemblages of graptolites so far found in New South Wales neither the lowermost nor the uppermost graptolite zone of the Ordovician as known in other parts of the world has as yet been recorded in this State, though zones in the Llandeilo and Caradoc are well represented.

In the Silurian, though the presence of only a few zones has been proved so far, new discoveries of Silurian graptolites recorded in this paper are of particular importance since they demonstrate the Silurian age of sedimentary rocks previously thought to belong to different systems, while on the other hand, Ordovician graptolites discovered recently at Parkes disprove in part the Silurian age previously assigned to rocks there.

Apart from the beds at Narrandera with *Tetragraptus quadribrachiatu*s, the oldest Ordovician graptolite-bearing slates so far known in the State belong to the zone of *Nemagraptus pertenuis*. It is characterised by small diplograptids such as *Glyptograptus teretiusculus*, *Orthograptus whitfieldi* and *Amplexograptus*.

Small dicranograptids are found, while the zone fossil and *Retiograptus geinitzianus* occur less commonly. Dendroids are also known.

In the succeeding zone of *Climacograptus peltifer*, what could be called a "burst" of *Climacograptus bicornis* and its allies usually appears. They are generally not large and are accompanied by a wealth of small dicellograptids, dicranograptids, lasiograptids and *Cryptograptus tricornis*. *Corynoides* sp. though so common in Europe and America at about this horizon has been found at one locality only.

The next zone, that of *Climacograptus wilsoni*, is marked by a profusion of diplograptids, all very much larger than those seen earlier. Climacograptids predominate in collections so far made and a large *Dicranograptus nicholsoni* sometimes occurs with them.

The zone of *Orthograptus calcaratus* and *Plegmatograptus nebula* is widely represented. Species of *Dicellograptus* and *Dicranograptus*, usually fairly large, are especially common as they are in the zone of *Dicranograptus clingani* in Britain. Since that species has not been recognized so far in New South Wales, its name is not used for the zone. *Orthograptus calcaratus* and its varieties are very common. *Climacograptus bicornis* is still found. *Leptograptus flaccidus* occurs for the first time and delicate Retiolitidae appear in force, especially *Plegmatograptus nebula*.

In the highest zone of the Ordovician so far recognised with certainty in New South Wales, *Orthograptus quadrimucronatus* is very widespread but the other zone fossil, *Pleurograptus linearis*, rather rare. *Climacograptus*

tubuliferus is frequently found and *Orthograptus truncatus pauperatus* occurs while some of the Retiolitidae survive.

In the lowest Silurian zone recognised so far in the State, that of *Monograptus gregarius*, very small diplograptids survive, accompanying early forms of monograptids including as well as the zone fossil, species of *Rastrites* with their characteristic isolated thecae.

In the succeeding zone of *Monograptus crispus*, near the top of the Llandovery, the diplograptids have gone and the monograptids which are found show more advanced development such as hooked thecae.

Above this in the Wenlock the cladia-bearing cyrtograptids appear accompanying *Monograptus priodon*, in the zone of *Cyrtograptus insectus*.

Beds with the very distinctive *Monograptus testis* and its variety, *inornatus*, and varieties of *Monograptus flemingi* mark the highest zone of the Wenlock, that of *Monograptus testis*.

The zone of *Monograptus nilssoni* of Lower Ludlow age has been recognised. It contains abundant *Monograptus bohemicus* as well as monograptids which have reverted to thecae of simple type developed on a straight stipe.

The highest zone so far found, that of *Monograptus scanicus*, contains little else but occasional small specimens of *Monograptus sakweyi*.

Acknowledgements

Professor C. E. Marshall has kindly allowed me to work at the Department of Geology and Geophysics of the University of Sydney, and I also wish to thank Miss F. M. Quodling of that University for help. Mr. H. O. Fletcher, Deputy Director of the Australian Museum, Mr. H. F. Whitworth, Curator of the Mining Museum, and Mr. T. J. O'Brien of the Water Board have been good enough to allow me to study specimens in their care. I am also indebted to Dr. N. C. Stevens, Mr. A. Miller, Mr. D. Maggs and Mr. A. Mangunwidjojo who have lent me specimens for study, and to my son, W. O. Sherrard, for help with photography.

Origin of Black Graptolite Slate

In New South Wales as well as elsewhere, Ordovician graptolites occur most commonly in black slates. Joplin noticed this association while making a detailed study of Ordovician rocks (1945). She analysed chemically eleven graptolite-bearing slates from New South Wales

and found that these contained a percentage of silica varying between 77 and 87, whereas the average slate contains about 60 per cent (Clarke, 1916). She concluded that this remarkably high percentage of silica must be due to the fact that the slates consist of deposits of volcanic ash or dust. She pictured "large volumes of volcanic ash . . . suddenly poured on the masses of plankton floating . . . in a geosyncline".

Later Öpik (1958) stated that all slates in the southern half of the area "shown on Joplin's map (of New South Wales) . . . contain the same fauna . . . It may be concluded that all the occurrences mentioned by Joplin are remnants of an extended blanket of a single deposit."

I have examined graptolites from nine of the eleven slates analysed by Joplin. I cannot agree that the deposits were formed at one time, nor do I agree with Öpik (op. cit., p. 18) that "the same fauna occur in a remnant of an extended blanket of a single deposit" (my italics).

As shown in my paper of 1954, the graptolites in the slates analysed by Joplin belong to four different zones of the Ordovician ranging from the zone of *Climacograptus peltifer* to that of *Orthograptus quadrimucronatus*. The time covered from the oldest to the youngest of these zones is considerable (Llandeilo and Caradoc). During that time there would need to have been at least four separate successive outpourings of volcanic ash burying the sediments containing each successive suite of graptolites, if Joplin's hypothesis is used to explain the high percentage of silica in each slate.

It seems unnecessary to postulate a series of ash showers to account for the high silica percentage in the slates. Carozzi (1960, p. 339) points out that cherts, cherty sandstones and cherty shales may form under normal oceanographic conditions. While in some cases the silica is of biochemical origin, in others it is a primary precipitate of silica gel. "Volcanism has been an additional factor but by no means an essential one."

Ordovician

ARENIG

Zone of *Tetragraptus quadribrachiatus*

Graptolites of the oldest zone in the Ordovician recorded up to the present in New South Wales have been found only at Narrandera. *Tetragraptus quadribrachiatus* was made the zone fossil of this collection in my previous paper (Sherrard, 1954) and the zone was placed in the

Arenig in conformity with Table VII of the Geology of Australia (David, ed. Browne, 1950) and with Elles (1937). Collecting since that paper's publication has not added any different species. Admittedly *T. quadribrachiatum* has too long a range to serve satisfactorily as a zone fossil, but no other graptolite occurring there is any more restricted and the zone name of *Tetragraptus quadribrachiatum* fulfils its required function in this case, that of indicating that this assemblage stands right apart from any other so far recorded from New South Wales.

LLANDEILO

Zone of Nemagraptus pertenuis

Graptolites have been known for many years from the neighbourhood of Junction Reefs in boulders from the Belubula River between Mandurama and Lyndhurst (Hall, 1900; Sherrard, 1954). Neither the early collection nor one made in 1959 was found *in situ*, but since the specimens were collected close to the headwaters of the river, they cannot have travelled far. *Dicranograptus tardiusculus*, a new record for Australia, suggests the top of the zone.

The new collection from Junction Reefs contains

Dicranograptus tardiusculus
Glyptograptus teretiusculus
Amplexograptus arctus.

Graptolite assemblages belonging to this zone were recorded (Sherrard, 1954) from about 12 miles west of Mandurama in the Malongulli Formation (Stevens, 1952). A rather different assemblage recently collected from Portion 110, Par. Carlton, in the same formation indicates the same zone. It is

Dicellograptus angulatus
Climacograptus scharenbergi (common)
 ? *Glyptograptus teretiusculus*
Cryptograptus tricornis.

From further upstream on the Belubula River in Portion 130, Par. Carlton, approximately 200 yards from the river, another new collection has yielded

Glyptograptus teretiusculus
 cf. *Lasiograptus costatus* or *Plegmatograptus nebula caudatus*
Dictyonema sp.

Dictyonema sp. in this collection has different dimensions from *D. salebrosum* Sherrard (1956) originally described from a neighbouring locality.

The collection contains several specimens of the graptolite here compared with *Lasiograptus* or *Plegmatograptus*. They have very long virgulas and strong apertural spines which are connected up into a well-developed regularly meshed lacinia such as is seen on *Plegmatograptus nebula caudatus*. Both full profile and scalariform views seem to be represented, sometimes in slight relief. Unfortunately none are well enough preserved for satisfactory study.

A collection made from Armour's Range, 5 miles north-west of Yerranderie Post-office, is from a place which was difficult of access even before it was isolated by the Warragamba Reservoir. It is a new locality for graptolites, of which the following are present:

Dicranograptus rectus
Glyptograptus teretiusculus
Amplexograptus arctus
 ? *Dictyonema* sp.

This assemblage fits well into the zone.

A collection listed in this zone in my previous paper from the Malongulli Formation included a graptolite identified as *Isograptus caduceus* var. *tenuis* Harris. Its thecae are tubes inclined at up to 25 degrees whose slightly concave ventral walls prolonged to a strong denticle show no sign (except in one or two distal thecae) of the sigmoid curvature seen in thecae of *Leptograptus* and *Dicellograptus* while their everted apertures are quite unlike the introverted and sometimes introverted apertures seen in thecae of those genera.

However, after publication of the paper, Dr. W. J. Harris, the author of the variety and an authority on the genus, kindly examined the specimen photographed for Plate X, fig. 5 (Sherrard, 1954) and disagreed with its identification as *Isograptus*. Consequently I suggested (Sherrard, 1956, p. 90) that it perhaps represents a transitional form not previously recorded. The shape of the thecae in the specimen under discussion seems to be that of the Dichograptidae, though the direction of growth of the earliest formed thecae which is at an angle of 20 degrees to the horizontal is perhaps suggestive of the Leptograptidae or Dicellograptidae (Elles, 1922, p. 171).

Discussing the descent of *Dicellograptus*, Bulman (1955, V71) has written "an independent origin from dichograptid stock cannot be excluded" (that is independent of *Leptograptus*).

Should more specimens similar to that illustrated be found in later collecting, a claim for their position as a transitional form between

the Dichograptidae and Leptograptidae would be strengthened. Dr. Thomas (1960, p. 6) maintains that the Isograptidae form such a link, though he does not agree that the graptolite under discussion is an *Isograptus* (personal communication).

Monsen (1937) has described a form transitional between the two families: *Didymograptus leptograptoides*, but it is distinct from that from the Malongulli Formation near Mandurama since Monsen's species has declined stipes diverging at less than 180 degrees, and its apertural margins lie in excavations, whereas the Mandurama specimen has reclined stipes and everted apertures. As a further distinction, Monsen's species is associated with graptolites belonging to a lower zone than that of *Nemagraptus pertenuis*.

CARADOC

Zone of Dicellograptus patulosus or Climacograptus peltifer

Graptolites in slates from a mine dump in Tomingley village were previously placed in the zone of *Nemagraptus pertenuis* (Sherrard, 1954, p. 81) though it was pointed out that the assemblage had many species characteristic of the next higher zone into which it is now placed.

The material at the dump heap had been obtained from steeply dipping strata 250 feet below the surface (note in Register of specimens at Mining Museum, Sydney). Recently graptolites have been collected *in situ* from slate outcropping at the surface in Tomingley Town Lot 3, Par. Gundong, Co. Narromine. This is not far from the mine shaft. The graptolites which occur in this new collection were also found and recorded by me from the Tomingley mine dump, but it is noteworthy that the new collection obtained at surface level contains no dendroid graptolites though these were remarkably abundant in the assemblage which came from 250 feet below and were described (Sherrard, 1956). The collection is:

Dicellograptus patulosus
Mesograptus multidentis
Glyptograptus teretiusculus
Orthograptus cf. calcaratus acutus.

An assemblage from Portion 6, Par. Clifford, Co. Beresford, near Cooma seems to fit best in this zone. It contains:

Dicellograptus angulatus
Climacograptus bicornis
C. ? scharenbergi
Orthograptus apiculatus.
Cryptograptus tricornis.

It resembles a collection from Par. Bullenbalong, also in the Cooma district, which was placed in this zone previously (Sherrard, 1954).

Zone of Climacograptus wilsoni

Assemblages of graptolites from two localities, Wagga and Mt. Tallebung, were placed with some hesitation in this zone previously (Sherrard, 1954). Since then slates with graptolites which undoubtedly belong to the zone of *Cl. wilsoni* have been found near Mt. Tallebung by officers of the Geological Survey.

The slate is coarse, breaks very unevenly and contains much chistalite but the following assemblage can be determined:

Dicranograptus nicholsoni
Climacograptus bicornis
C. tridentatus
C. wilsoni or *tridentatus*
C. ? scharenbergi
Orthograptus ? vulgatus.

Though there is still doubt as to whether the zone fossil is present in the assemblage, there can be no doubt of the zone. Apart from the representative fossils, the presence of swarms of diplograptids clearly indicates it (Elles, 1925, p. 342).

The graptolite appearing in the list as *Climacograptus wilsoni* or *tridentatus* has in two cases a large diamond-shaped vesicle attached to its proximal end (pl. 1, figs. 4, 5). It is of a similar white chitinous substance to that of the rhabdosome. It has a suggestion of a comparatively coarse reticulate structure. Across its axes, the vesicle measures 1 cm. Spines project 3 mm. beyond two of the angles. The proximal end of the rhabdosome can be seen within the vesicle. It appears as though it was originally a flat, square object at right angles to the plane of the rhabdosome and possibly touching it. Compression has caused the appearance as in the plate. Literature on graptolites contains some discussion on the shape and function of discs such as this which are occasionally seen attached to rhabdosomes. The disc on the climacograptid from Mt. Tallebung is much the same shape as the discs seen supporting the synrhabdosomes of Ruedemann (1895), which are fully discussed by Kozłowski (1948), though since these discs occur at the distal ends of rhabdosomes, their purpose cannot have been similar.

T. S. Hall (1906) when establishing the species, *Climacograptus baragwanathi*, described the sac at the proximal end of its rhabdosome as having an ill-defined margin and consisting of a net-

work of apparently branching and anastomosing fibres, which, he said, distinguished it from some Diplograptidae with suspended sacs with well-defined margins figured by Lapworth. Hall was apparently referring to Lapworth, 1876, plate II, fig. 46, *Climacograptus wilsoni* with a suspended elliptical sac.

He was writing before the publication of that part of the Monograph of British Graptolites which included a description of *Climacograptus wilsoni* with a "sac . . . commonly elliptical in form (which) may measure 10 by 5 mm. . . and is often a flattened, irregularly shaped body" (Elles and Wood, 1906, p. 199). Miss Elles subsequently considered (David, 1932) that *C. baragwanathi* was a synonym for *C. wilsoni*, though Harris and Thomas (1955) do not agree.

In the case of *Climacograptus antiquus bursifer*, the sac is supported at some distance from the proximal end of the rhabdosome. A central disc of a regular shape surrounds the proximal ends of the stipes of certain Dichograptids, for example *Loganograptus* (Bulman, 1955, fig. 52, 2). Miss Elles states (1944, note p. 146) she regards as "floats the disc-like structures often visible and enveloping the proximal region" of dichograptids.

A membrane frequently surrounds each spine in *Climacograptus tridentatus* giving it an appearance of greater width, but illustrations do not show these membranes coalescing into a diamond-shaped figure as in plate 1, figs. 4, 5. However, since spines protrude from each angle of the diamond, this graptolite under discussion seems to approach most closely to a *Climacograptus tridentatus* where secondary thickening has been carried to an extreme extent. *C. tridentatus* is characteristic of the same zone as is *C. wilsoni*.

C. tridentatus is also represented at Mt. Tallebung in normal development with characteristic virgella and somewhat thickened basal spines. In still other cases a "vesicle" at the proximal end of a diplograptid is apparently only a fragment of another rhabdosome.

Greatly distorted diplograptids collected 12 miles north of Mt. Tallebung may be *Orthograptus* ? *calcaratus vulgatus*. Fragments which are incomplete at either end are up to 8 cm. long and others are 5 mm. wide. A broad virgular tube within the rhabdosome and the thecal shape are characters of the *calcaratus* group. It is noticeable that where graptolite rhabdosomes are lying at right angles to each other on the same slab, one set is about twice as wide as the other set lying at right angles,

though as far as can be told from the poor preservation all specimens are probably *Orthograptus* ? *vulgatus*. This difference in breadth suggests differences in compression directions.

Orthograptus vulgatus over 7 cm. long has also been collected, without associates, from Portion 110, Par. Carlton. It must come from higher in the Malongulli Formation than does the assemblage from this portion dominated by *Cl. scharenbergi* which was placed in a lower zone.

Zone of Orthograptus calcaratus and Plegmatograptus nebula

Many years ago well-preserved graptolites were collected for the Geological Survey of New South Wales in the south-east of the State in the County of Wellesley (Dun, 1897) and described by T. S. Hall (1902). These assemblages were placed in this zone by me (Sherrard, 1954).

Examination of the recent collections made in these areas by the Geological Survey has confirmed this allocation. In addition a more precise definition of localities is possible. The locality "Five miles from Delegate" (Sherrard, 1954, p. 86) (sometimes known as Ingram's) must be very close to the new collecting places, Slate Quarry, Portion 44, Par. Delegate, and Portion 38, Par. Delegate, because these are both about 5 miles north of Delegate township and are close to portions of the parish held in the name of Ann Ingram. These localities are approximately 20 miles east of the Parishes of Alexander (through which flows Stockyard Flat Creek) and of Tingaringi, which are also graptolite localities (Sherrard, 1954, p. 86). The Parish of Lawson (*Nemagraptus pertenuis* zone in Sherrard, 1954) is about 15 miles east of Delegate.

The locality Stockyard Flat Creek is sometimes referred to as Stockyard Creek (Hall, 1902), while a misprint in my paper disguises it as Stockyard Flat Flat (Sherrard, 1954). A Lands Department plan of the Parish of Alexander (dated 1935) shows Stockyard Flat Creek and Stockyard Creek as separate tributaries of Little River. The recent collections were from near the junction of Little River and Stockyard Flat Creek.

The Stockyard Flat Creek collections are rich in Dicollograptids. This is characteristic of the British zone of *Dicranograptus clingani* to which my zone of *Orthograptus calcaratus* is equivalent.

Study of extensive collections made from a quarry in the Cobargo district has shown that

the assemblage from there should be placed in this zone not in a later one as was done in my previous paper, when few specimens were available.

A collection of graptolites from near the Tolwong Mine, Shoalhaven Gorge, kindly made available by the Curator of the Mining Museum, shows this assemblage belongs to this zone rather than to that of *Climacograptus peltifer*, into which it was placed on the basis of the graptolites available for study in 1954.

Diplograptus thieli T.S.H. and *D. carnei* T.S.H. were recorded from this locality (Hall, 1920). They are now regarded as synonyms of *Orthograptus truncatus* Lapworth (Harris and Thomas, 1955). Harris and Thomas also write (1955) "it seems preferable to discard the variety *apertus* of the species *Dicranograptus hians* T.S.H." This variety was first described from Tolwong Mine (Hall, 1909).

I consider *Diplograptus linearis* T.S.H., also first described from Tolwong, is a synonym of *Orthograptus calcaratus basilicus* (fig. 1c), as is shown in Systematic Descriptions below. The form recorded by T. S. Hall from Tolwong as *Diplograptus foliaceus* corresponds to *Orthograptus calcaratus vulgatus* as understood at the present day because of the width of the rhabdosome, the shape of the thecae and their number per centimetre, the spines on basal thecae and the fact that the excavation is more conspicuous distally than proximally, which is the reverse of the condition in *Diplograptus foliaceus* as restricted at present from its former much wider limits.

Zone of Orthograptus quadrimucronatus and Pleurograptus linearis

Recent collections from Quaama and from the Adaminaby Dam Site, Parishes of Nimmo and Eucumbene, Co. Wallace, justify the placing in this zone of graptolite assemblages which previously could not be zoned on account of the few fossils found. A new discovery of graptolites in sandy shale about 16 miles north-east of Braidwood near the Nerriga-Mongarlowe road, at First Currodex Creek, Portion 149, Par. Mongarlowe, also falls into this zone. Graptolites recently collected near Parkes in rocks hitherto assigned to the Silurian (David, 1950) are characteristic of the top of this zone, if not of that above.

There is a strong representation in New South Wales of scandent graptolites with an attenuated periderm such as are found in the families Lasiograptidae Bulman 1955 and Retiolitidae Lapworth 1873. The placing of some of these

fossils in their correct genera is a matter of considerable difficulty on account of their rather poor preservation in New South Wales rocks and their extreme delicacy. The distinction between actual rhabdosome and lacinia is consequently often masked. Identification is aided when the zone is indicated by graptolites accompanying the forms with attenuated periderms. This is the case in a collection from a new locality, Glenfergus State Forest, 7 miles north-east of Cooma. Here a wide graptolite with an attenuated periderm is accompanied by both the type fossils of this zone as well as by others commonly found in it. Since the accompanying graptolites are no wider than normal, the unusual

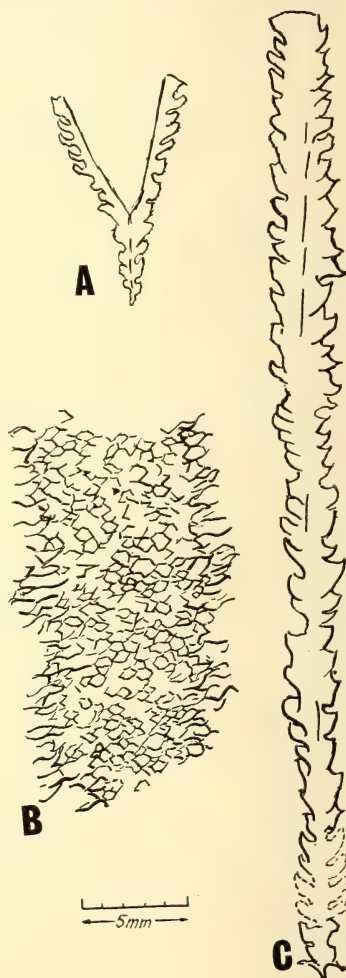


FIG. 1

- 1A. *Dicranograptus rectus* Hopk. Yerranderie No. F 46626, Australian Museum.
- 1B. *Plegmatograptus nebula caudatus* (T. S. Hall). Glenfergus State Forest, Mining Museum No. 12503.
- 1C. *Orthograptus calcaratus basilicus* Lapw. Tolwong Mine No. F 11588, Mining Museum.

width of the form with attenuated periderm (7.5 mm., fig. 1B.) cannot be due to distortion of the slate in which it occurs. It is considered to be *Plegmatograptus nebula caudatus* (T. S. Hall).

T. S. Hall described and figured a new species, *Retiolites caudatus* from Stockyard Flat Creek (1902, pl. xiv, fig. 6), while *Retiolites* (*Plegmatograptus*) *nebula* was erected in 1908 by Elles and Wood. Hall's species *R. caudatus*, though

TABLE I

Localities in Zone of *Orthograptus calcaratus* and *Plegmatograptus nebula*

Form	Locality				
	1	2	3	4	5
<i>Leptograptus flaccidus</i> Hall ..				×	
<i>L. capillaris</i> Carr. ..			×		
<i>Dicellograptus angulatus</i> E. & W.				×	
<i>D. morrisoni</i> Hopk. ..		×			×
<i>D. elegans</i> Carr. ..				×	
<i>D. caduceus</i> Lapw. ..				×	
<i>D. forchhammeri</i> Gein. ..					×
<i>D. forchhammeri flexuosus</i> Lapw.		×	×		
<i>Dicranograptus nicholsoni</i> Hopk. ..	×		×	×	
<i>D. furcatus minimus</i> Lapw. ..	×				
<i>D. hians</i> T. S. Hall ..	×		×	×	
<i>D. ramosus spinifer</i> Lapw. ..			×	×	
<i>Climacograptus tubuliferus</i> Lapw.				×	
<i>C. caudatus</i> Lapw. ..			×	×	×
<i>C. minimus</i> (Carr.) ..		×		×	
<i>C. bicornis</i> Hall ..		×	v.c.	×	×
<i>C. peltifer</i> Lapw. ..			×	×	
<i>Orthograptus calcaratus</i> Lapw. ..	×	×			
<i>O. calcaratus vulgatus</i> Lapw. ..				×	
<i>O. calcaratus basilicus</i> Lapw. ..				×	
<i>O. truncatus</i> Lapw. ..				×	
<i>O. truncatus intermedius</i> E. & W.			×		cf.
<i>O. pageanus</i> Lapw. ..			×		
<i>O. pageanus abnormis spinosus</i> E. & W. ..				×	
<i>O. apiculatus</i> E. & W. ..	×		×		
<i>Retiograptus yassensis</i> Sherrard & Keble ..				×	
<i>Plegmatograptus nebula</i> E. & W. ..	×		×	×	
<i>P. nebula caudatus</i> (T. S. Hall) ..	×		×	×	
<i>Glossograptus hincksii</i> Hopk. ..	×				
<i>Neurograptus margaritatus</i> Lapw. ..	×				
<i>N. fibratus</i> Lapw. ..				×	
<i>Cryptograptus tricornis</i> Carr. ..		v.c.		×	

Key to Locality Numbers :

1. Junction of Stockyard Flat Creek and Little River, Par. Alexander, Co. Wellesley.
2. Portions 38 and 44, Par. Delegate and "Ingram's", 5 miles from Delegate, Co. Wellesley.
3. Road material quarry, approximately 7.8 miles west of Bermagui and 7 miles east of Cobargo, Portion 176, Par. Bermagui.
4. Tolwong Mine, Shoalhaven River. (Mining Museum Collection)
5. Larbert, Upper Shoalhaven River, 10 miles north-west of Braidwood.

rather larger than *R. nebula*, was taken as identical with it by Miss Elles in her notes on Table A, facing page 41 of the Explanatory Notes (David, 1932). By that time *Plegmatograptus nebula* was well-established, but Dr. W. J. Harris and Dr. D. E. Thomas have pointed out (personal communication) that Dr. T. S. Hall's name, description and exquisite figure of *Retiolites caudatus* published in 1902 should give his specific name priority over *Plegmatograptus nebula* Elles and Wood, 1908. The dimensions given by Hall for *Retiolites caudatus* would evidently cover the "larger and wider form which . . . may . . . be separated off as a distinct variety" referred to and illustrated by Elles and Wood (1908, p. 341, pl. xxxiv, fig. 14D). Consequently this name is used for the wide variety from Glenfergus State Forest because of its correspondence in dimensions and general description. It should be said, however, that the form from Glenfergus, which is incomplete, may be without the virgula and virgella which are each prolonged 1.5 cm. beyond the body of *R. caudatus* illustrated by T. S. Hall.

? *Glyptograptus sinuatus*, which has been doubtfully identified from the Parish of Montagu, adjacent to Glenfergus State Forest, is recorded from the Bolindian of Victoria (Thomas, 1960), though it does not occur below the Silurian in Britain.

The finding near Parkes of graptolites belonging to this zone or the next above confirms the mapping by Andrews (1910) of rocks of Ordovician age in the immediate neighbourhood of the town. The shale containing Ordovician graptolites outcrops very sparingly and fossils were not found there until recently. Since Silurian fossils were well known from west of the town, workers after Andrews assigned a Silurian age to the whole Forbes-Parkes gold-bearing belt (David, 1950). It is now shown that both Ordovician and Silurian rocks occur. The finding of a lamellibranch, possibly a pterinoid, with the graptolites is of further interest.

OTHER ORDOVICIAN OCCURRENCES

Collections of graptolites of Ordovician age from other localities which have been examined are too poorly preserved for precise zoning but can all be provisionally assigned to the Caradoc.

These include :

1. Carboona Gap, between Jingellic and Tumbarumba, 18 miles south-west of Tumbarumba

Orthograptus pageanus

Climacograptus ? *caudatus* or ? *wilsoni*.

Diplograptids occur at each of the following localities :

- 2. Portion 145, Par. Coppabella, Co. Goulburn, 17 miles east of Holbrook and about 10 miles west of Carboona Gap.
- 3. Portions 34 and 35, Par. Ramsay, Co. Bourke.
- 4. Portion 29, Par. Jillett, Co. Bourke (eastern end)
- 5. Portion 27, Par. Flinders, Co. Beresford
- 6. Jingerangle State Forest, Par. Jingerangle, Co. Bland
- 7. Gibber Trig., Par. Jingerangle, Co. Bland
- 8. Portions 52 and 53, Par. Umaralla, Co. Beresford
- 9. In addition to these, a soft, partly bleached shale outcropping near Bateman's Bay at Surf (Ocean) Beach, south of the mouth of the Clyde River may contain a ? graptolite of a ? retiolid character.

Dr. A. A. Öpik, who most kindly made this specimen, found by him, available for record, states that chert occurs immediately beneath the shale.

Silurian

Graptolites of this age have been found in two localities which were previously unknown as graptolite-bearing, nor were they known to be of Silurian age. A third example is from a locality already mapped as Silurian (Joplin, 1952).

LOWER LLANDOVERY

Zone of Monograptus gregarius

An assemblage kindly put at my disposal by Dr. N. C. Stevens contains besides the type form a number of very narrow (one millimetre or less) diplograptids. The assemblage is :

- Monograptus gregarius* (common)
- M. atavus*
- M. cf. triangulatus triangulatus*
- Glyptograptus tamariscus*
- Climacograptus innotatus*
- ? *Dimorphograptus erectus*.

This assemblage from The Glen, Canomodine, about 5 miles south of Cargo, proves definitely the Silurian age of the Millambri Formation

TABLE II
Localities in Zone of *Orthograptus quadrimucronatus* and *Pleurograptus linearis*

Form	Locality							
	1	2	3	4	5	6	7	8
<i>Leptograptus flaccidus</i> Hall	..	×	×				×	×
<i>Pleurograptus linearis</i> Carr.	..	×						
<i>Dicellograptus morrisi</i> Hopk.	..	×	×				×	
<i>D. elegans</i> Carr.	..	×			×	×		
<i>D. pumilus</i> Lapw.	..	×	×		×			
<i>D. complanatus ornatus</i> E. & W.	..		×			×		×
<i>D. caduceus</i> Lapw.	..		×					
<i>D. anceps</i> Nich.	..							?
<i>Dicranograptus hians</i> T. S. Hall	..	×				×		
<i>D. ramosus</i> (Hall)	..					×		
<i>Climacograptus tubuliferus</i> Lapw.	..		×		×	×		×
<i>C. caudatus</i> Lapw.	..					×		
<i>C. hughesi</i> (Nich.)	..							?
<i>Orthograptus quadrimucronatus</i> Hall	..	×	?	×		×		?
<i>O. calcaratus</i> Lapw.	..	×				×		
<i>O. calcaratus vulgatus</i> Lapw.	..		×					
<i>O. truncatus pauperatus</i> E. & W.	..		×	×		×	×	×
<i>Glyptograptus sinuatus</i> Nich.	..				?			
<i>Retiograptus yassensis</i> Sherrard & Keble	..	×			×			
<i>Plegmatograptus nebula caudatus</i> (T. S. Hall)	..	×						

Key to Locality Numbers

- 1. Glenfergus State Forest, Par. Umaralla, Co. Beresford
- 2. Adaminaby Dam site, Pars. Nimmo and Eucumbene
- 3. Quaama, 3 miles east of village, head of Cadjangarry Creek, 1¼ m. SW Cadjangarry Trig., Co. Dampier
- 4. Nerriga-Mongarlowe road, First Currodux Creek, about Portion 149, Par. Mongarlowe, about 16 miles N.E. Braidwood
- 5. Portion 1A, Par. Montagu, Co. Beresford
- 6. Portion 1, Par. Umaralla, Co. Beresford
- 7. Portion 124, Par. Callaghan, Co. Beresford
- 8. Parkes, 1 mile (about) north of post office and ½ mile east of Newell Highway.

at that locality, although it has been mapped as ? Ordovician (Stevens, 1957). It corresponds approximately with the lower Keilorian beds of Victoria.

Short fragments of rhabdosomes are compared with *Monograptus triangulatus triangulatus* (Harkness) as defined by Margaret Sudbury (1958, 1959). These fragments are generally straight and vary in width from 0.25 mm. to 0.6 mm. apart from thecae. Including thecae they are 1 mm. wide. The thecae are triangulate to rastriform, 7–13 in 10 mm. They occur in a coarse-grained arenaceous rock into which the thecae are embedded in some cases. This assemblage falls into the sub-zone of *M. triangulatus*-*M. fimbriatus*, the lower of the two into which Margaret Sudbury (1958) considers that the zone of *M. gregarius* should be divided.

UPPER WENLOCK

Zone of Monograptus testis

Monograptus testis (Barrande) indicating the zone of that name at the top of the Wenlock has been collected by Mr. D. Maggs of the University of New South Wales, near Cumnock, about 35 miles north-north-west of Canomodine, the locality mentioned immediately above. At Cumnock, Mr. Maggs has collected *M. testis* throughout a conformable series of about 100 feet of shales in which brachiopods and trilobites also occur. Though *M. testis* from Cumnock does not attain the large dimensions given in Barrande's diagnosis (1850) which set up the species, the long spines on the graptolites from Cumnock indicate the species and not the variety, *inornatus*.

M. testis var. *inornatus* was collected from Ginninderra (Sherrard, 1952), where it also came from a sequence of rocks containing brachiopods and trilobites.

M. cf. testis has also been recorded at Quarry Creek (Packham and Stevens, 1955), which is a locality between Cumnock and Canomodine.

LOWER LUDLOW

Zone of Monograptus nilssoni

Blue slate found in rough country, four and a half miles west-north-west of Yerranderie Post-office, on Billy's Creek, a tributary of the Kowmung River, shows a prolific occurrence of poorly preserved graptolites. The main slaty cleavage of the rock is at a slight angle to the bedding. All the graptolites seem to belong to one species, though none is complete proximally. It is probably *Monograptus cf. varians pumilus*.

None of the specimens is more than one centimetre long, the virgula is often conspicuous and the thecae widen near the aperture. These characteristics as well as its appearance in profusion suggest this variety.

Systematic Descriptions

Order GRAPTOLIDEA

Family DICRANOGRAPTIDAE

Dicellograptus complanatus ornatus E. & W.

Plate 1, Fig. 1

Dicellograptus complanatus ornatus E. & W., Elles and Wood, 1904, 140, pl. xx, figs. 2a-c.

Stipes 2 cm. long, increasing in width from 0.4 mm. to 0.7 mm., straight, diverging from square axil at 290 degrees. Sicula blunt and conspicuous. Thecae 10 in 10 mm., apertures introverted. Conspicuous lateral spines 3 mm. long.

Associate: *Orthograptus quadrimucronatus*.

Localities: Adaminaby, Parkes.

Dicellograptus patulosus Lapworth

Plate 1, Fig. 2

Dicellograptus patulosus Lapworth, Elles and Wood, 1904, 147, pl. xxi, figs. 5a-e.

Stipes 4 cm. long, 0.4 mm. wide, proximally increasing to 1 mm. wide, curving slightly. Axil wide, axillary angle 120 degrees. Sicula not seen, faint basal spines. Thecae 7–8 in 10 mm., each 2.5 mm. long, 0.4 mm. wide, narrowing towards aperture, which is introverted. Overlap two-thirds, deep and narrow excavation.

Associates: *Mesograptus foliaceus*, *Orthograptus calcaratus acutus*, Dendroids.

Locality: Tomingley Mine Dump.

Dicranograptus tardiusculus Lapw.

Plate 1, Fig. 3

Dicellograptus patulosus Lapworth, Elles and Wood, 1904, 167, pl. xxiv, fig. 2.

Biserial portion 6 mm. long, increasing in width from 0.6 mm. to 1.5 mm. Uniserial stipes, straight, 1.5 cm. long and 1 mm. wide. Axillary angle 40 degrees, axil pointed. Ten biserial thecae, alternate, with mesial spines sometimes seen. Twelve uniserial thecae per 10 mm., 1.5 long, mesial spines on some, overlap one-quarter. Ventral wall strongly curved. Excavation very pronounced, up to 0.6 mm. deep. Basal spines visible but not virgella. It is regarded as

D. tarduisculus rather than *D. rectus* because of the very well-marked excavations.

Associate: *Amplexograptus arctus*.

Locality: Junction Reefs, Mandurama.

Dicranograptus cf. *rectus* Hopk.

Fig. 1A

Dicranograptus rectus Hopk., Elles and Wood, 1904, 169, pl. xxiv, fig. 4.

Biserial section 5 mm. long, 0.6 mm. wide proximally, 2 mm. wide at bifurcation, thecae alternate, spined, 2 mm. long, overlap one-third, 10 in 10 mm., ventral wall undulate, faint septum. Axillary angle, 50 degrees. Trace of web between uniserial stipes. Uniserial stipe seems to continue direction of biserial. Uniserial stipe 1 mm. wide, 10 thecae in 10 mm., 2.5 mm. long, overlap one-third, slightly curved ventral wall.

Associate: *Glyptograptus teretiusculus*.

Locality: Yerranderie.

Dicranograptus furcatus var. *minimus* Lapw.

Dicranograptus furcatus var. *minimus* Lapw., Elles and Wood, 1904, 179, pl. xxv, fig. 4.

Biserial section 3 mm. long, 0.8 mm. wide proximally and 1.1 mm. at bifurcation. Four thecae on each side with curving ventral walls and introverted apertures, faint spines, slender virgella. Axillary angle 25 degrees. Uniserial stipes 1 mm. wide, about 1.5 cm. long, curving back towards each other but not meeting. Stipe twisted so that thecae shown on inside. This twisting appears only to be known in *Dicranograptus ziczac* and its varieties. Var. *minimus* Lapw. was transferred by Elles and Wood (1904) to *Dicranograptus furcatus* J. Hall. from *D. ziczac* Lapw. Uniserial thecae 12 in 10 mm., ventral walls strongly curved, 2 mm. long, overlap two-thirds, faint spines on some thecae. Miss Elles (personal communication) considered some specimens identified by me as this variety were *Dicranograptus brevicaulus*, but the stipes were untwisted in such cases. Locality: Stockyard Flat Creek.

Family DIPLOGRAPTIDAE

Climacograptus tridentatus Lapw. or
wilsoni Lapw.

Plate 1, Figs. 4, 5

Climacograptus bicornis var. *tridentatus* Lapw., Elles and Wood, 1906, 195, pl. xxvi, fig. 9.

Climacograptus wilsoni Lapw., Elles and Wood, 1906, 197, pl. xxvi, fig. 12.

Rhabdosome incomplete distally, broken at 1.5 cm. in case of specimens with best preserved vesicles. Other specimens attain length of 5 cm. but are incomplete proximally. Width 0.6 mm. proximally, increasing to 3 mm. Septum present. Thecae 12 in 10 mm. with straight ventral wall, which is at first slightly inclined inward and then bends abruptly inward at the apertural angle so that a semi-circular excavation is formed between the lower theca and that adjoining above. Thecae less than 2 mm. long, overlap between one-third and one-half. The proximal appendage is described fully elsewhere in this paper.

Associate: *Dicranograptus nicholsoni*.

Locality: Mt. Tallebung Mine, 40 miles west of Condobolin.

Climacograptus scharenbergi Lapw.

Plate 1, Fig. 11

Climacograptus scharenbergi Lapw., Elles and Wood, 1906, 206, pl. xxvii, fig. 14.

Rhabdosomes up to 1 cm. long, broad virgula prolonged 1 cm. Width distally 1.4 mm. Thecae distinctly alternate, 15 in 10 mm., 1.5 mm. long, overlap one-third to one-half, ventral wall sigmoidally curved with abrupt bend halfway along. Excavation one-third width of rhabdosome. Apertural margins sometimes concave and introverted. Virgella 0.5 mm. long. Septal groove zig-zag, but discontinuous.

Associates: *Dicellograptus angulatus*, *Cryptograptus tricornis*.

Locality: Portion 110, Parish of Carlton; Co. Bathurst, Mandurama District.

Orthograptus calcaratus basilicus Lapw.

Fig. 1c

Orthograptus calcaratus basilicus Lapw., Elles and Wood, 1907, 243, pl. xxx, figs. 2a-d.

Diplograptus (*Mesograptus*) *linearis* T. S. Hall, 1920, Rec. Geol. Surv. N.S.W., 9, 65. No figure. Rhabdosome up to 3.5 cm. long, 1 mm. wide proximally, 2.8 mm. wide distally. Fine curving basal spines, 1 mm. long, virgella 0.5 mm. long. Thecae 11 in 10 proximally, 8 in 10 distally; 2 mm. long, 0.4 mm. wide, overlap one-half. Excavation one-quarter. Ventral margin of thecae sigmoid, apertural margin convex, small denticle. Interrupted fine septum.

Associate: *Leptograptus flaccidus*.

Locality: Tolwong Mine.

Orthograptus truncatus pauperatus Elles and Wood

Plate 1, Fig. 6

Orthograptus truncatus pauperatus E. & W., Elles and Wood, 1907, 237, pl. xxix, figs. 5a-d.

Rhabdosome 3 cm. long where broken at edge of slab; 0.8 mm. wide proximally, 2.5 mm. distally (1 cm. from proximal end). Thecae 13 in 10 mm., very strongly everted, 1.5 to 2 mm. long, 0.6 mm. wide, overlap one-third. Thecae alternate, inclined at 40 degrees to vertical. Ventral wall of thecae, sigmoidally curved, apertural margin often hollowed out. Thecal walls not very clearly seen. Apertural angle forms an almost spine-like denticle. No septum. Excavation very marked, one-fifth width of rhabdosome on each side. Basal spines sometimes seen.

Associate: *Orthograptus quadrimucronatus*.

Locality: Mongarlowe.

Amplexograptus arctus Elles and Wood

Plate 1, Figs. 7, 8

Amplexograptus arctus E. & W., Elles and Wood, 1907, 271, pl. xxxi, figs. 16a-d.

Length up to 3 cm., width 0.5 mm, proximally increasing to 1.5 mm. Thecae 11 in 10 mm., alternate. Excavation one-third to one-quarter width of rhabdosome. Septum present. Virgella 2-6 mm. long, though the longest is broken.

The specimens identified as *A. arctus* are rather large for this species, but they have not enough thecae per centimetre for *Amplexograptus perexcavatus*, nor is a septum known in the latter species.

Associate: *Dicranograptus tardiusculus*.

Locality: Junction Reefs, Mandurama.

Family RETIOLITIDAE

Plegmatograptus nebula caudatus (T. S. Hall)

Fig. 1B

Retiolites caudatus T. S. Hall, 1902, 56, pl. xiv, fig. 6.*Retiolites* (*Plegmatograptus*) *nebula* E. & W., Elles and Wood, 1908, 340, pl. xxxiv, fig. 14d.

Rhabdosome, incomplete, proximally and distally, reticulate periderm. Length 1.5 cm., width 7.5 mm. at its widest, narrowing slightly to 6.5 mm. at either end. The exact walls of the rhabdosome are difficult to detect in the mass of the lacinia, though they seem to be about 5.5 mm. apart. The clathria cannot be detected. Thecae are of diplograptid shape, alternate, 12 in 10 mm. and without a periderm,

each about 1.5 mm. long, overlapping one-half. Aperture concave. The rhabdosome is covered by a fine reticulate mesh, generally arranged in a hexagonal pattern. From either wall of the rhabdosome branches out a lacinia formed of a series of spines, some mesial, some apertural. A faint membranous film, also reticulate, seems to cover the lacinia in places such as is mentioned by Elles and Wood (p. 341). This may be due, however, to the superposition of another fossil of the same delicate nature. The whole appearance of the fossil is reminiscent of the Silurian graptolite, *Pseudoplegmatoraptus obesus* (Lapworth) (fig. 66, 7, Bulman, 1955) which Pribyl (1948) makes the genotype of a new genus. The Glenfergus graptolite is, probably however, best described as the broad form of *Retiolites* (*Plegmatograptus*) *nebula* referred to by Elles and Wood (p. 341) as "eventually (to) be separated off as a distinct variety". Poorly preserved though this specimen is, it is more complete than are most specimens of *Plegmatograptus* found in New South Wales. Ordovician *Retiograptus* and *Retiolites* illustrated by Ruedemann (1947, pls. 80 and 83) are probably related.

It is not unlikely that wide graptolites found at Captain's Flat, New South Wales, with few and indefinite associates and described (Sherrard, 1954) as *Mesograptus* cf. *multidens* largely on account of what appeared to be the Mesograptid-like shape of the thecae, may also belong here. Plate 1, fig. 9, illustrates what may be a scalariform view of a Captain's Flat fossil with well-developed clathria.

Associates: *Pleurograptus linearis*, *Orthograptus quadrimucronatus*.

Locality: Glenfergus State Forest, Par. Umaralla.

Family MONOGRAPTIDAE

Monograptus testis (Barrande)

Plate 1, Fig. 10

Graptolithus testis Barrande, Grapt. de Bohème, 1850, 53, pl. 3, figs. 19-21.

Rhabdosomes ventrally curved, about 4 cm. long, width at extreme proximal end, 0.25 mm. increasing to just over 2 mm. wide. Sricula sometimes visible. Thecae 9-12 in 10 mm., up to 2.3 mm. long, 0.6 mm. wide, inclined at 30 degrees to axis. The apertural region is either curved forward into a hook (the retroverted apertural region mentioned by Elles and Wood for *M. testis* var. *inornatus* (1913, p. 446)) or sometimes apparently has an aperture at

right angles to the thecal length with a thin spine 2 mm. long proceeding from the lower angle. It is very likely that these differing appearances are due to the method of preservation, the hook may or may not be buried in the rock. In other cases the rhabdosome is preserved in scalariform view with long spines occasionally seen to proceed out on either side. Growth lines are sometimes noticeable encircling thecae.

Locality : 2 miles west of Cumnock.

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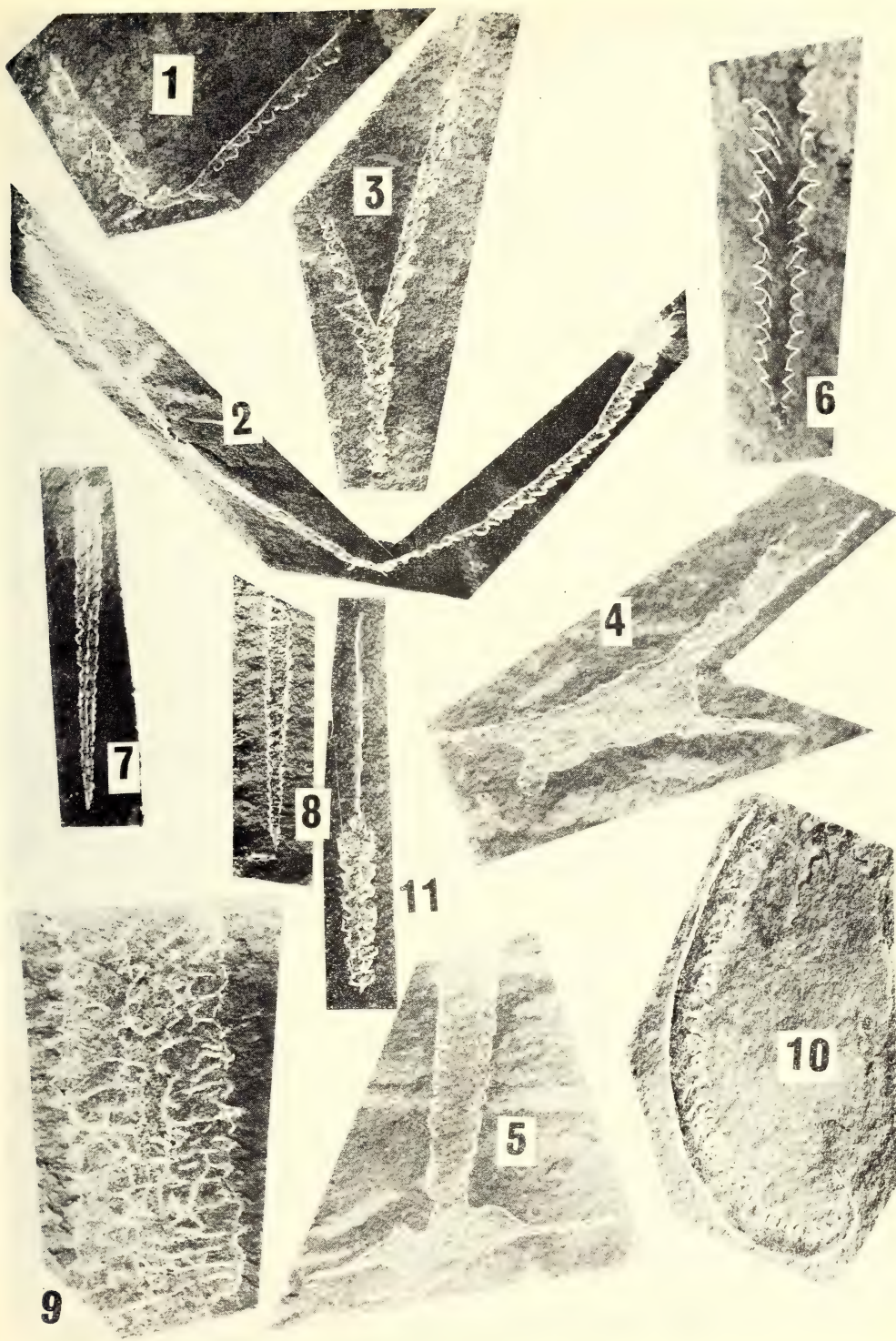
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Explanation of Plate I

All retouched. Magnification $\times 2$ except Nos. 9 and 11, which are $\times 3$.

1. *Dicellograptus complanatus ornatus* E. & W. Adaminaby, A.M. No. F 46136.
2. *Dicellograptus patulosus* Lapw. Tomingley Mine Dump, A.M. No. F 49385.
3. *Dicranograptus tardiusculus* Lapw. Junction Reefs, Mandurama, Mining Museum No. F 12505.
- 4, 5. *Climacograptus tridentatis* Lapw. or *wilsoni* Lapw., Mt. Tallebung, A.M. No. F 47307.
6. *Orthograptus truncatus pauperatus* E. & W. Mongarlowe, Mining Museum No. F 12504.
- 7, 8. *Amplexograptus arctus* E. & W. Junction Reefs, Mandurama, Mining Museum No. F 12506.
9. ? *Plegmatograptus nebula caudatus* (T. S. Hall), scalariform view, Captain's Flat, A.M. No. F 49386.
10. *Monograptus testis* (Barr.). Cumnock.
11. *Climacograptus scharenbergi* Lapw., Portion 110, Par. Carlton.

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VICK, C. G., 1934. *Astr. Nach.*, 253, 277.

The abbreviated form of the title of this journal is: *J. Proc. Roy. Soc. N.S.W.*

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Whenever possible dye-line or photographic copies of each diagram should be sent so that the originals need not be sent to referees, thus eliminating possible damage to the diagrams while in the mail.

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PART 6

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The Royal Society of New South Wales originated in 1821 as the "Philosophical Society of Australasia"; after an interval of inactivity it was resuscitated in 1850 under the name of the "Australian Philosophical Society", by which title it was known until 1856, when the name was changed to the "Philosophical Society of New South Wales". In 1866, by the sanction of Her Most Gracious Majesty Queen Victoria, the Society assumed its present title, and was incorporated by Act of Parliament of New South Wales in 1881.

Precise Observations of Minor Planets at Sydney Observatory During 1959 and 1960

W. H. ROBERTSON
Sydney Observatory, Sydney

The programme of precise observations of selected minor planets which was begun in 1955 is being continued and the results for 1959 and 1960 are given here. The methods of observation and reduction were described in the first paper (Robertson 1958). All the plates were taken with the 9-inch camera by Taylor, Taylor and Hobson (scale 116" to the millimetre). Four exposures were made on each plate. For the plates of **4 Vesta** a coarse wire grating was placed in front of the lens giving first order spectra which are 2.3 magnitudes fainter than the central image and displaced 0.32 mm from it in an east-west direction. The spectra were measured for the planet and the central image for the stars.

In Table I are given the means for all four images for the separate groups of stars at the mean of the times. The differences between the results average 0^s.023 sec δ in right ascension and 0".34 in declination. This corresponds to probable errors for the mean of the two results from one plate of 0^s.010 sec δ and 0".14. The result from the first two exposures was compared with that from the last two by adding the

movement computed from the ephemeris. The means of the differences were 0^s.011 sec δ in right ascension and 0".12 in declination. No correction has been applied for aberration, light time or parallax but the factors give the parallax correction when divided by the distance.

In accordance with the recommendation of Commission 20 of the International Astronomical Union, Table II gives for each observation the positions of the reference stars and the dependences. The columns headed "R.A." and "Dec." give the seconds of time and arc with proper motion correction applied to bring the catalogue position to the epoch of the plate. The column headed "Star" gives the number from the *Yale Catalogue* (Vols. 11, 12 I, 12 II, 13 I, 13 II, 14, 16). The majority of the plates were measured by Miss W. Bellamy, Miss J. Hawkes, Mrs. Y. Lake and Mrs. M. Wilson, who have also assisted in the reductions.

Reference

ROBERTSON, W. H., 1958. *J. Proc. Roy. Soc. N.S.W.*, 92, 18; *Sydney Observatory Papers* 33.

TABLE I

		R.A. (1950.0)			Dec. (1950.0)			Parallax Factors	
		h	m	s	°	'	"	s	"
1 Ceres									
1959 U.T.									
241	Apr.	6.69827	15	49	28.110	-10	25	56.10	-0.006 -3.47 S
242	Apr.	6.69827	15	49	28.101	-10	25	56.22	
243	Apr.	22.65873	15	40	55.099	-10	10	40.66	+0.025 -3.50 R
244	Apr.	22.65873	15	40	55.135	-10	10	40.26	
245	Apr.	30.63791	15	34	39.398	-10	03	58.43	+0.042 -3.52 R
246	Apr.	30.63791	15	34	39.452	-10	03	58.33	
247	May	28.53455	15	09	33.560	-10	07	23.36	+0.012 -3.51 R
248	May	28.53455	15	09	33.543	-10	07	23.53	
249	June	11.50622	14	59	46.114	-10	34	08.05	+0.064 -3.46 S
250	June	11.50622	14	59	46.146	-10	34	07.96	
251	June	19.46182	14	56	03.650	-10	57	57.38	+0.002 -3.39 S
252	June	19.46182	14	56	03.660	-10	57	57.81	
253	July	1.42637	14	53	23.030	-11	44	42.74	0.000 -3.28 R
254	July	1.42637	14	53	23.060	-11	44	42.88	
255	July	2.42210	14	53	19.229	-11	49	08.65	-0.005 -3.27 W
256	July	2.42210	14	53	19.264	-11	49	08.26	

TABLE I—*continued*

			R.A. (1950.0)			Dec. (1950.0)			Parallax Factors		
			h	m	s	°	'	"	s	"	
257	July	10.41703	14	53	41.609	-12	27	27.66	+0.047	-3.18	S
258	July	10.41703	14	53	41.616	-12	27	27.64			
259	July	22.38937	14	57	02.392	-13	32	36.24	+0.056	-3.03	R
260	July	22.38937	14	57	02.400	-13	32	36.22			
261	July	27.36995	14	59	20.386	-14	01	52.78	+0.033	-2.96	S
262	July	27.36995	14	59	20.386	-14	01	53.02			
263	July	31.36334	15	01	32.502	-14	26	04.85	+0.041	-2.90	S
264	July	31.36334	15	01	32.474	-14	26	04.88			
265	Aug.	4.34975	15	04	02.694	-14	50	48.57	+0.028	-2.84	W
266	Aug.	4.34975	15	04	02.676	-14	50	48.27			
267	Aug.	5.35473	15	04	43.426	-14	57	06.79	+0.051	-2.83	S
268	Aug.	5.35473	15	04	43.382	-14	57	06.38			
39 Laetitia											
1959 U.T.											
269	June	18.72237	21	09	02.508	-7	04	45.45	+0.001	-3.94	W
270	June	18.72237	21	09	02.499	-7	04	45.27			
271	June	25.70017	21	08	23.282	-7	08	47.46	-0.007	-3.93	R
272	June	25.70017	21	08	23.302	-7	08	47.60			
273	July	2.68017	21	06	34.010	-7	21	17.91	-0.006	-3.90	W
274	July	2.68017	21	06	34.006	-7	21	17.32			
275	July	9.67195	21	03	37.084	-7	42	38.32	+0.034	-3.86	W
276	July	9.67195	21	03	37.090	-7	42	38.08			
277	July	22.63372	20	55	39.156	-8	44	42.76	+0.042	-3.72	S
278	July	22.63372	20	55	39.166	-8	44	42.34			
279	July	23.61875	20	54	56.628	-8	50	30.90	+0.006	-3.70	S
280	July	23.61875	20	54	56.606	-8	50	30.82			
281	July	27.60725	20	51	57.858	-9	15	21.34	+0.011	-3.64	W
282	July	27.60725	20	51	57.869	-9	15	21.52			
283	Aug.	4.57151	20	45	41.616	-10	10	25.98	-0.019	-3.51	R
284	Aug.	4.57151	20	45	41.588	-10	10	26.28			
285	Aug.	13.54982	20	38	39.652	-11	18	03.47	+0.005	-3.35	S
286	Aug.	13.54982	20	38	39.636	-11	18	04.33			
287	Aug.	21.50879	20	33	02.467	-12	19	19.46	+0.043	-3.21	S
288	Aug.	21.50879	20	33	02.448	-12	19	19.68			
289	Sep.	11.46863	20	24	05.742	-14	45	04.48	+0.031	-2.77	S
290	Sep.	11.46863	20	24	05.768	-14	45	05.12			
291	Sep.	23.42541	20	24	04.788	-15	47	51.56	-0.003	-2.71	R
292	Sep.	23.42541	20	24	04.786	-15	47	50.74			
293	Sep.	28.43308	20	25	14.130	-16	08	40.82	+0.063	-2.67	S
294	Sep.	28.43308	20	25	14.134	-16	08	40.66			
295	Sep.	30.41737	20	25	52.876	-16	15	59.25	+0.029	-2.64	S
296	Sep.	30.41737	20	25	52.844	-16	15	59.33			
297	Oct.	7.39796	20	28	58.070	-16	37	28.94	+0.021	-2.59	S
298	Oct.	7.39796	20	28	58.057	-16	37	28.88			
299	Oct.	13.38781	20	32	35.088	-16	50	37.15	+0.033	-2.55	W
300	Oct.	13.38781	20	32	35.076	-16	50	37.76			
40 Harmonia											
1959 U.T.											
301	May	28.68164	19	00	36.176	-22	00	27.68	-0.030	-1.78	R
302	May	28.68164	19	00	36.048	-22	00	28.40			
303	June	11.65437	18	52	03.618	-22	40	44.02	+0.026	-1.68	S
304	June	11.65437	18	52	03.660	-22	40	44.46			
305	June	17.64370	18	46	45.028	-23	00	36.04	+0.058	-1.65	W
306	June	17.64370	18	46	45.068	-23	00	36.26			
307	June	18.61550	18	45	49.036	-23	03	54.34	-0.025	-1.63	W
308	June	18.61550	18	45	49.056	-23	03	53.68			
309	June	25.60941	18	38	39.443	-23	27	38.00	+0.035	-1.57	R
310	June	25.60941	18	38	39.416	-23	27	38.35			
311	July	27.49786	18	07	59.964	-24	54	11.03	+0.025	-1.35	W
312	July	27.49786	18	07	59.934	-24	54	10.78			

TABLE I—*continued*

			R.A. (1950.0)	Dec. (1950.0)	Parallax Factors		
			h m s	° ' "	s	"	
313	July	29.47894	18 06 48.750	-24 57 53.23	-0.018	-1.33	S
314	July	29.47894	18 06 48.718	-24 57 54.42			
315	Aug.	4.47234	18 04 00.783	-25 08 04.00	+0.022	-1.31	R
316	Aug.	4.47234	18 04 00.796	-25 08 04.70			
317	Aug.	19.41140	18 02 33.341	-25 27 53.54	-0.042	-1.27	S
318	Aug.	19.41140	18 02 33.316	-25 27 53.52			
319	Sep.	15.37031	18 18 32.946	-25 45 53.56	+0.031	-1.22	W
320	Sep.	15.37031	18 18 32.918	-25 45 53.29			

1 Ceres

1960 U.T.

321	May	31.80042	22 12 27.931	-20 46 39.81	-0.042	-1.98	W
322	May	31.80042	22 12 27.949	-20 46 40.25			
323	June	7.78751	22 16 09.306	-21 00 22.23	-0.030	-1.94	R
324	June	7.78751	22 16 09.252	-21 00 22.56			
325	June	15.78304	22 19 11.870	-21 23 55.47	+0.020	-1.88	S
326	June	15.78304	22 19 11.868	-21 23 55.70			
327	June	23.75564	22 20 52.071	-21 55 59.48	-0.002	-1.80	W
328	June	23.75564	22 20 52.122	-21 55 59.67			
329	July	4.73010	22 20 46.100	-22 53 28.52	+0.013	-1.66	S
330	July	4.73010	22 20 46.094	-22 53 29.13			
331	July	18.67691	22 16 31.828	-24 24 14.05	-0.027	-1.43	R
332	July	18.67691	22 16 31.828	-24 24 13.93			
333	Aug.	3.63939	22 06 31.076	-26 17 29.27	+0.017	-1.14	W
334	Aug.	3.63939	22 06 31.114	-26 17 29.71			
335	Aug.	8.61888	22 02 33.203	-26 50 58.34	+0.003	-1.05	R
336	Aug.	8.61888	22 02 33.188	-26 50 58.11			
337	Aug.	16.60242	21 55 43.476	-27 39 31.89	+0.041	-0.94	S
338	Aug.	16.60242	21 55 43.517	-27 39 32.63			
339	Aug.	22.58273	21 50 28.288	-28 10 12.74	+0.039	-0.86	W
340	Aug.	22.58273	21 50 28.277	-28 10 13.20			
341	Aug.	29.54924	21 44 30.786	-28 38 21.85	+0.004	-0.78	R
342	Aug.	29.54924	21 44 30.786	-28 38 21.40			
343	Sep.	5.53077	21 39 01.602	-28 57 32.60	+0.019	-0.73	
344	Sep.	5.53077	21 39 01.572	-28 57 32.40			
345	Sep.	20.49178	21 30 04.688	-29 07 47.20	+0.048	-0.72	R
346	Sep.	20.49178	21 30 04.758	-29 07 47.60			
347	Sep.	28.45049	21 27 21.312	-28 57 17.65	-0.014	-0.73	R
348	Sep.	28.45049	21 27 21.292	-28 57 18.08			
349	Oct.	5.42239	21 26 15.791	-28 40 14.70	-0.042	-0.78	S
350	Oct.	5.42239	21 26 15.746	-28 40 13.64			
351	Oct.	27.38831	21 30 29.470	-27 08 15.68	+0.038	-1.02	W
352	Oct.	27.38831	21 30 29.440	-27 08 15.04			

4 Vesta

1960 U.T.

353	Apr.	27.77458	19 03 32.570	-18 32 47.39	-0.002	-2.30	R
354	Apr.	27.77458	19 03 32.612	-18 32 47.86			
355	May	9.75183	19 10 10.428	-18 41 35.56	+0.015	-2.28	W
356	May	9.75183	19 10 10.436	-18 41 35.49			
357	May	30.69648	19 10 45.156	-19 32 20.03	+0.021	-2.15	W
358	May	30.69648	19 10 45.187	-19 32 20.20			
359	May	31.68923	19 10 24.748	-19 36 00.32	+0.007	-2.14	W
360	May	31.68923	19 10 24.714	-19 36 00.41			
361	June	7.66138	19 07 07.001	-20 04 54.06	-0.014	-2.07	R
362	June	7.66138	19 07 07.000	-20 04 53.78			
363	June	15.65862	19 01 33.861	-20 43 50.70	+0.061	-1.99	S
364	June	15.65862	19 01 33.857	-20 43 51.42			
365	June	23.61815	18 54 32.137	-21 26 55.44	+0.016	-1.87	W
366	June	23.61815	18 54 32.156	-21 26 55.62			
367	July	4.58697	18 43 33.680	-22 28 38.00	+0.037	-1.72	S
368	July	4.58697	18 43 33.686	-22 28 37.78			

TABLE I—*continued*

			R.A. (1950.0) h m s	Dec. (1950.0) ° ' "	Parallax Factors s "
369	July	18.52088	18 30 20.441	−23 41 54.52	−0.025 −1.53 R
370	July	18.52088	18 30 20.462	−23 41 54.04	
371	July	27.50784	18 23 50.310	−24 22 31.77	+0.029 −1.43 S
372	July	27.50784	18 23 50.314	−24 22 31.74	
373	Aug.	3.47022	18 20 28.130	−24 49 48.86	−0.026 −1.36 S
374	Aug.	3.47022	18 20 28.068	−24 49 48.95	
375	Aug.	11.46628	18 18 37.303	−25 16 43.21	+0.038 −1.29 W
376	Aug.	11.46628	18 18 37.294	−25 16 43.55	
377	Aug.	16.44435	18 18 35.665	−25 31 09.98	+0.011 −1.25 W
378	Aug.	16.44435	18 18 35.645	−25 31 09.88	
379	Aug.	22.43267	18 19 41.746	−25 46 17.26	+0.025 −1.21 W
380	Aug.	22.43267	18 19 41.699	−25 46 17.61	
381	Sep.	1.40562	18 24 09.930	−26 06 07.96	+0.015 −1.11 W
382	Sep.	1.40562	18 24 09.894	−26 06 08.10	
383	Sep.	6.39196	18 27 32.411	−26 13 33.60	+0.007 −1.14 W
384	Sep.	6.39196	18 27 32.441	−26 13 34.34	
18 Melpomene					
1960 U.T.					
385	May	4.78435	20 11 02.980	− 9 44 33.67	−0.058 −3.59 S
386	May	4.78435	20 11 02.922	− 9 44 34.48	
387	May	10.77865	20 16 18.632	− 9 16 03.98	−0.036 −3.64 W
388	May	10.77865	20 16 18.683	− 9 16 03.44	
389	May	31.73177	20 28 43.085	− 7 57 34.04	−0.028 −3.82 W
390	May	31.73177	20 28 43.057	− 7 57 33.71	
391	June	7.71262	20 30 25.630	− 7 43 00.28	−0.033 −3.86 R
392	June	7.71262	20 30 25.644	− 7 43 00.40	
393	June	15.68612	20 30 42.390	− 7 36 25.27	−0.049 −3.87 S
394	June	15.68612	20 30 42.412	− 7 36 25.46	
395	June	23.68276	20 29 05.588	− 7 42 38.57	+0.012 −3.86 W
396	June	23.68276	20 29 05.570	− 7 42 38.75	
397	July	4.65082	20 23 50.190	− 8 15 11.18	+0.018 −3.78 S
398	July	4.65082	20 23 50.219	− 8 15 11.50	
399	July	18.59706	20 12 57.344	− 9 38 12.68	−0.007 −3.59 R
400	July	18.59706	20 12 57.351	− 9 38 12.59	
401	July	27.56678	20 04 31.928	−10 53 07.99	−0.007 −3.41 S
402	July	27.56678	20 04 31.936	−10 53 07.18	
403	Aug.	3.55084	19 57 58.495	−11 59 26.89	+0.017 −3.25 W
404	Aug.	3.55084	19 57 58.470	−11 59 26.86	
405	Aug.	8.53700	19 53 36.738	−12 49 12.90	+0.026 −3.14 R
406	Aug.	8.53700	19 53 36.724	−12 49 12.82	
407	Aug.	16.52288	19 47 38.766	−14 10 00.25	+0.064 −2.96 S
408	Aug.	16.52288	19 47 38.837	−14 10 00.59	
409	Aug.	22.49350	19 44 19.533	−15 09 04.16	+0.030 −2.80 W
410	Aug.	22.49350	19 44 19.498	−15 09 03.94	
411	Sep.	1.45367	19 41 30.524	−16 40 36.64	−0.004 −2.57 W
412	Sep.	1.45367	19 41 30.536	−16 40 36.32	
413	Sep.	6.44477	19 41 29.792	−17 21 52.98	+0.012 −2.48 W
414	Sep.	6.44477	19 41 29.778	−17 21 53.68	
415	Oct.	5.38979	19 59 31.686	−20 02 23.10	+0.050 −2.09 S
416	Oct.	5.38979	19 59 31.678	−20 02 23.14	
417	Oct.	11.38189	20 06 40.760	−20 17 11.08	+0.062 −2.06 W
418	Oct.	11.38189	20 06 40.740	−20 17 10.70	

TABLE II

No.	Star	Depend.	R.A. s	Dec. "	No.	Star	Depend.	R.A. s	Dec. "
241	5500	0·376024	28·089	49·09	262	5230	0·290498	52·625	11·19
	5527	0·198688	46·150	02·86		5274	0·331746	43·103	27·73
	5525	0·425288	13·581	15·83		5553	0·377756	27·251	10·84
242	5518	0·208605	31·693	07·54	263	5242	0·239686	30·730	33·91
	5505	0·274173	13·324	25·94		5298	0·313613	16·670	34·32
	5517	0·517142	54·734	33·05		5553	0·446701	27·251	10·84
243	5470	0·184813	00·992	27·80	264	5536	0·382510	09·172	44·22
	5496	0·364222	35·127	22·69		5572	0·283802	38·796	29·45
	5477	0·450966	21·802	19·86		5279	0·333688	46·836	27·81
244	5468	0·180254	48·896	26·16	265	5545	0·336034	52·476	16·47
	5494	0·248884	05·139	59·65		5576	0·327116	12·211	05·78
	5480	0·570862	16·328	20·48		5581	0·336850	05·517	01·32
245	5424	0·256310	34·307	10·54	266	5553	0·144825	27·251	10·84
	5463	0·412350	47·779	24·16		5570	0·488090	21·544	35·99
	5457	0·331340	41·321	16·91		5572	0·367085	38·796	29·45
246	5423	0·306924	27·643	45·12	267	5553	0·186323	27·251	10·84
	5458	0·276782	52·192	07·16		5570	0·482240	21·544	35·99
	5470	0·416294	00·992	27·80		5581	0·331437	05·517	01·32
247	5286	0·190293	33·507	54·35	268	5545	0·312368	52·476	16·47
	5318	0·336913	15·136	26·52		5566	0·256112	49·937	51·12
	5324	0·472794	46·466	40·43		5588	0·431520	45·392	17·85
248	5297	0·375498	52·849	12·86	269	7584	0·428663	07·858	28·82
	5312	0·366945	37·018	59·38		7604	0·308578	11·427	03·98
	5346	0·257558	49·140	04·91		7634	0·262760	37·305	03·91
249	5255	0·260372	10·751	56·40	270	7590	0·287729	03·253	26·00
	5271	0·380672	10·803	26·98		7591	0·393854	23·345	20·91
	5267	0·358956	08·981	47·80		7629	0·318416	52·901	16·63
250	5252	0·492026	57·122	04·29	271	7584	0·312214	07·858	28·82
	5275	0·140294	56·541	13·97		7593	0·370378	45·717	47·20
	5278	0·367680	42·725	09·08		7619	0·317408	20·407	37·05
251	5240	0·290386	21·351	32·98	272	7590	0·335466	03·253	26·00
	5246	0·426154	48·852	58·42		7591	0·282832	23·345	20·91
	5254	0·283460	09·211	30·39		7614	0·381702	17·976	52·02
252	5235	0·346364	19·322	23·92	273	7571	0·252464	16·109	48·06
	5252	0·406249	57·122	04·30		7580	0·426503	06·887	16·55
	5253	0·247387	01·702	41·09		7614	0·321034	17·976	52·02
253	5211	0·285078	38·190	06·47	274	7564	0·274924	38·225	01·54
	5223	0·378514	57·982	34·70		7573	0·350888	27·233	15·93
	5253	0·336408	01·702	41·09		7615	0·374187	42·152	34·20
254	5212	0·343950	44·630	57·48	275	7550	0·367630	28·695	48·06
	5236	0·388960	29·249	35·21		7563	0·399474	35·015	29·43
	5249	0·267089	28·756	26·08		7590	0·232896	03·253	26·00
255	5211	0·257387	38·190	06·47	276	7559	0·351368	03·844	42·15
	5223	0·444516	57·982	34·70		7566	0·299805	49·603	03·86
	5253	0·298096	01·702	41·09		7568	0·348827	59·850	22·83
256	5214	0·314924	09·444	45·69	277	7502	0·367044	52·786	06·25
	5235	0·497388	19·322	23·92		7522	0·272028	15·247	21·38
	5247	0·187688	58·334	08·12		7536	0·360927	00·859	27·05
257	5214	0·407806	09·445	45·69	278	7506	0·266674	32·609	24·15
	5229	0·322209	42·664	12·58		7521	0·408354	13·392	40·03
	5265	0·269985	00·732	18·89		7525	0·324972	39·982	25·00
258	5224	0·388972	02·795	15·33	279	7502	0·381276	52·786	06·26
	5226	0·405366	09·522	34·91		7520	0·238808	12·197	37·69
	5247	0·205661	58·335	08·12		7521	0·379917	13·392	40·03
259	5224	0·399818	02·795	15·33	280	7490	0·410475	42·105	08·00
	5274	0·260791	43·103	27·73		7522	0·273746	15·247	21·38
	5536	0·339391	09·172	44·22		7536	0·315779	00·859	27·05
260	5225	0·361225	08·121	56·33	281	7473	0·239950	47·523	24·83
	5262	0·345433	43·011	34·75		7481	0·360036	40·422	07·32
	5545	0·293342	52·476	16·47		7511	0·400014	25·593	10·47
261	5242	0·306546	30·730	33·91	282	7380	0·308706	23·604	40·00
	5279	0·310979	46·837	27·81		7491	0·344123	47·037	00·40
	5542	0·382474	36·457	30·34		7520	0·347171	12·197	37·69

TABLE II—*continued*

No.	Star	Depend.	R.A. s	Dec. "	No.	Star	Depend.	R.A. s	Dec. "
283	7357	0·297313	57·182	48·20	304	13114	0·275766	45·144	14·22
	7358	0·270693	01·661	12·31		13134	0·388882	26·738	22·68
	7382	0·431994	56·163	11·24		13172	0·335352	40·044	49·33
284	7356	0·194584	56·378	44·21	305	13042	0·312596	11·165	18·64
	7370	0·403706	45·644	07·61		13085	0·305776	54·329	35·50
	7374	0·401710	28·541	35·66		13086	0·381628	55·781	30·81
285	7310	0·402901	44·203	57·29	306	13053	0·343654	00·519	59·83
	7314	0·305034	47·317	23·51		13057	0·28158)	13·718	56·43
	7343	0·292066	13·260	45·72		13110	0·374766	29·381	13·06
286	7295	0·372651	32·824	44·84	307	13039	0·277964	03·721	52·91
	7326	0·278572	06·899	17·45		13042	0·293529	11·165	18·64
	7342	0·348777	53·512	31·55		13090	0·428506	04·466	40·68
287	7264	0·330280	03·191	23·22	308	13044	0·407170	12·987	38·43
	7265	0·250838	03·682	23·25		13057	0·288962	13·718	56·43
	7304	0·418882	47·435	54·56		13098	0·303868	31·369	29·71
288	7269	0·348656	32·621	06·47	309	12942	0·387378	56·749	00·58
	7278	0·379126	34·976	02·84		12992	0·431721	02·300	05·83
	7303	0·272217	35·934	21·17		13005	0·180901	09·737	37·93
289	7685	0·366014	12·046	20·60	310	12949	0·483660	37·284	14·40
	7687	0·284632	16·789	07·09		12959	0·222566	31·252	10·21
	7705	0·349354	41·943	03·44		13024	0·293773	53·061	45·21
290	7672	0·377268	15·455	51·50	311	12510	0·486419	50·091	01·95
	7703	0·355947	29·454	22·49		12556	0·248312	28·957	53·03
	7709	0·266785	14·416	38·22		12598	0·265269	31·977	52·62
291	7676	0·325848	42·889	24·91	312	12532	0·336764	51·387	45·75
	7697	0·378291	25·511	46·85		12541	0·358642	22·362	49·40
	7708	0·295861	14·424	46·50		12578	0·304594	59·982	14·53
292	7678	0·308908	29·565	49·44	313	12485	0·278026	28·865	39·08
	7685	0·421850	12·046	20·61		12502	0·343628	11·307	19·15
	7711	0·269242	17·220	13·61		12578	0·378346	59·982	14·53
293	7678	0·392228	29·565	49·44	314	12466	0·349473	27·731	58·77
	7709	0·273848	14·417	38·22		12510	0·358876	50·091	01·95
	7714	0·333924	37·596	30·14		12607	0·291652	01·279	17·49
294	7688	0·510856	26·259	23·81	315	12456	0·315589	56·666	39·11
	7701	0·183010	05·473	53·54		12463	0·445128	14·643	03·65
	7719	0·306134	19·743	38·07		12532	0·239283	51·387	45·75
295	7678	0·284611	29·565	49·44	316	12395	0·224058	21·114	08·39
	7701	0·242440	05·473	53·54		12497	0·436882	55·046	24·30
	7719	0·472949	19·743	38·07		12503	0·339060	15·980	25·00
296	7695	0·353870	17·137	53·51	317	12369	0·219156	15·946	07·88
	7697	0·346048	25·512	46·85		12463	0·499206	14·643	03·65
	7725	0·300082	26·410	04·67		12472	0·281639	53·142	01·88
297	7708	0·228516	14·424	46·50	318	12414	0·299576	01·863	06·46
	7713	0·390733	34·490	59·82		12432	0·289805	24·266	49·98
	7748	0·380751	01·303	11·98		12485	0·410619	28·865	39·07
298	7711	0·217755	17·215	13·61	319	12690	0·264424	04·445	11·23
	7724	0·343416	25·862	39·57		12705	0·493958	24·772	05·51
	7725	0·438829	26·410	04·63		12737	0·241618	26·813	53·31
299	7732	0·279492	15·759	49·11	320	12667	0·358866	35·784	22·33
	7737	0·412844	23·430	15·90		12728	0·355888	31·147	58·01
	7775	0·307664	17·685	50·98		12748	0·285245	03·186	29·81
300	7724	0·365614	25·863	39·57	321	9438	0·351970	59·228	17·57
	7757	0·299010	35·356	39·91		9449	0·314514	42·932	52·19
	7766	0·335376	07·447	13·41		9474	0·333516	47·454	45·34
301	13188	0·274010	49·145	34·34	322	9428	0·265171	57·833	10·26
	13284	0·350821	25·682	28·95		9456	0·350697	20·285	39·94
	8056	0·375168	31·306	51·93		9473	0·384132	41·882	13·88
302	13217	0·352252	17·293	21·73	323	9450	0·248349	43·810	33·29
	13257	0·279380	14·414	03·59		9479	0·411410	11·747	07·74
	8069	0·368369	33·972	50·27		9483	0·340241	07·011	10·35
303	13110	0·404095	29·381	13·06	324	9459	0·308650	55·153	33·84
	13136	0·268806	28·519	45·61		9478	0·355914	04·059	53·51
	13185	0·327099	43·089	33·35		9488	0·335436	12·858	52·52

TABLE II—*continued*

No.	Star	Depend.	R.A. s	Dec. "	No.	Star	Depend.	R.A. s	Dec. "
325	15192	0·279486	24·244	08·19	346	14108	0·501854	26·952	35·50
	15212	0·152949	31·423	04·59		14136	0·210842	52·790	24·74
	9487	0·567564	57·785	12·06		14163	0·287303	04·847	03·79
326	15169	0·378074	28·833	38·90	347	14071	0·233468	33·331	10·61
	15221	0·349070	53·021	11·87		14106	0·468400	10·862	48·58
	9490	0·272855	38·101	27·72		14133	0·298132	35·236	43·73
327	9488	0·255020	12·859	52·52	348	14092	0·242715	48·461	25·14
	15201	0·483220	58·883	38·51		14094	0·340052	50·873	13·05
	15233	0·261760	07·033	53·39		14126	0·417233	29·114	10·02
328	15173	0·283710	11·493	44·79	349	14075	0·379320	49·842	20·06
	15239	0·301457	04·503	32·81		14092	0·332443	48·460	25·14
	9494	0·414833	01·015	13·03		14128	0·288236	59·061	21·03
329	15196	0·365016	51·737	26·86	350	14074	0·262285	45·855	45·96
	15213	0·420606	36·634	41·02		14096	0·481542	54·522	41·60
	15217	0·214378	21·447	23·42		14126	0·256173	29·111	10·02
330	15184	0·329744	33·047	17·77	351	14122	0·439665	02·226	44·32
	15208	0·297950	09·308	39·78		14132	0·238808	14·555	50·51
	15226	0·372306	18·310	49·45		14155	0·321526	39·632	20·67
331	15166	0·319550	45·293	29·62	352	14112	0·268594	06·111	37·06
	15180	0·475196	53·658	27·66		14146	0·322921	45·016	19·37
	15194	0·205254	27·532	05·35		14824	0·408485	03·887	04·94
332	15152	0·205008	31·075	22·90	353	7061	0·467818	52·049	39·39
	15171	0·442463	42·403	53·91		8076	0·303100	14·713	50·72
	15200	0·352529	54·216	42·86		8138	0·229083	40·439	44·73
333	15081	0·366152	16·264	01·91	354	8045	0·331591	13·626	59·47
	15115	0·332045	48·451	07·25		8100	0·314458	16·642	32·89
	15126	0·301804	02·218	22·19		7097	0·353950	02·771	53·91
334	15084	0·243760	25·429	10·10	355	8138	0·420321	40·439	44·74
	15118	0·497734	12·849	15·63		8139	0·259887	49·358	25·33
	14406	0·258506	10·253	18·95		8184	0·319792	14·688	29·59
335	14365	0·327494	31·613	52·83	356	8105	0·254158	48·389	00·59
	14379	0·232929	23·827	32·49		8166	0·338684	27·848	19·80
	14393	0·439577	08·761	58·30		8171	0·407157	49·256	50·49
336	14359	0·313221	50·328	32·38	357	8149	0·383972	41·424	48·75
	14406	0·323184	10·253	18·95		8151	0·259538	48·471	10·35
	15066	0·363595	40·065	35·75		8179	0·356490	35·164	20·63
337	14318	0·254479	05·685	59·06	358	8139	0·366194	49·358	25·33
	14320	0·466492	09·057	14·67		8171	0·257719	49·257	50·49
	14359	0·279029	50·327	32·38		8173	0·376088	54·371	17·88
338	14313	0·246410	30·350	30·39	359	8133	0·448322	16·152	03·95
	14324	0·447130	46·784	32·21		8171	0·280528	49·257	50·49
	14352	0·306461	54·435	43·60		8178	0·271149	29·644	30·13
339	14273	0·339494	11·547	23·96	360	8139	0·401896	49·358	25·33
	14290	0·345884	48·241	16·45		8179	0·333256	35·165	20·63
	14306	0·314622	33·673	27·56		8152	0·264848	05·328	31·42
340	14279	0·310207	53·437	39·56	361	8108	0·432824	55·822	45·55
	14282	0·448095	36·847	03·05		8123	0·338642	53·556	57·55
	14318	0·241698	05·685	59·06		8149	0·228534	41·514	48·56
341	14228	0·420891	35·185	28·55	362	8100	0·303652	16·622	32·56
	14244	0·363612	22·518	00·38		8125	0·341326	33·491	12·86
	14275	0·215497	30·731	27·02		8133	0·355021	16·146	03·59
342	14229	0·444840	38·900	19·67	363	8024	0·220914	36·244	52·89
	14248	0·273464	47·788	59·05		8076	0·523108	14·649	50·16
	14266	0·281696	10·538	26·71		8091	0·255977	25·972	36·38
343	14176	0·323990	36·911	11·98	364	8038	0·240600	08·252	30·28
	14181	0·320421	33·352	41·79		8067	0·508502	20·893	24·24
	14244	0·355589	22·517	00·39		8100	0·250898	16·623	32·56
344	14189	0·308052	29·918	14·01	365	13141	0·275408	52·883	04·56
	14190	0·403368	36·111	31·64		13225	0·356740	59·510	56·81
	14229	0·288580	38·902	19·67		7983	0·367852	13·922	17·74
345	14106	0·224974	10·862	48·58	366	7966	0·393350	39·545	51·69
	14121	0·441669	01·938	33·19		8042	0·195142	49·242	28·24
	14160	0·333357	25·710	35·94		13191	0·411507	13·096	21·97

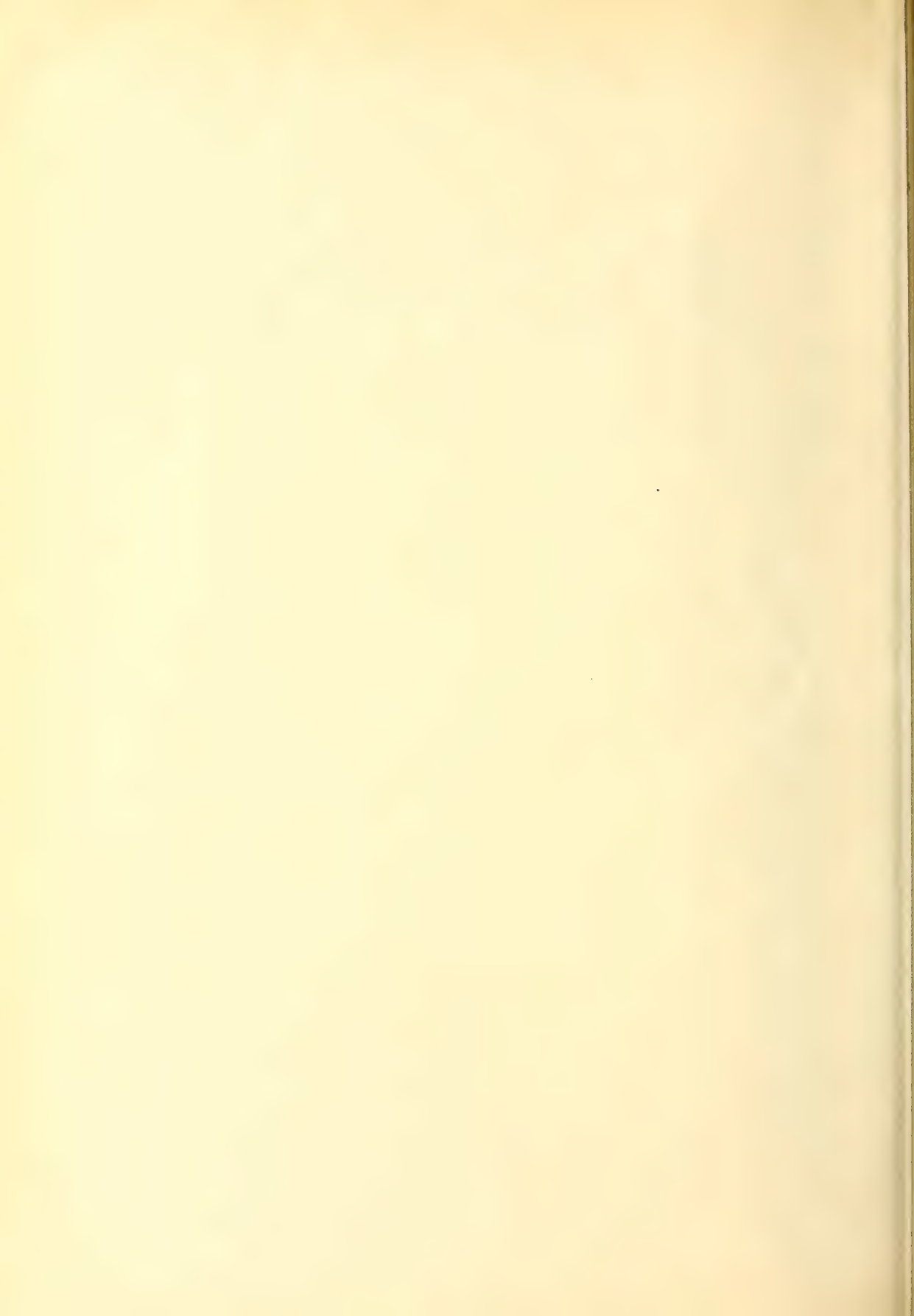
TABLE II—*continued*

No.	Star	Depend.	R.A. s	Dec. "	No.	Star	Depend.	R.A. s	Dec. "
367	13010	0·335962	22·345	09·50	388	7142	0·284160	04·445	15·73
	13082	0·308414	39·628	32·52		7185	0·484265	03·920	34·11
	7873	0·355625	03·890	32·27		7182	0·231575	56·349	59·93
368	13000	0·337055	41·612	14·77	389	7271	0·375170	12·744	09·14
	13074	0·385008	10·659	24·32		7294	0·264626	39·785	21·44
	7872	0·277938	02·953	50·85		7313	0·360203	21·986	09·95
369	12833	0·349646	18·081	06·77	390	7282	0·430190	36·374	56·30
	12871	0·440582	32·014	47·15		7291	0·275942	13·743	13·38
	12912	0·209772	20·294	07·70		7309	0·293867	48·152	39·35
370	12824	0·418433	26·883	08·58	391	7298	0·486238	41·901	24·41
	12847	0·241056	03·518	08·96		7309	0·278517	48·152	39·35
	12929	0·340511	47·934	27·54		7314	0·235245	29·365	17·90
371	12749	0·275705	01·276	44·81	392	7291	0·263288	13·743	13·38
	12772	0·325924	19·304	40·71		7299	0·367684	44·513	00·02
	12808	0·398371	12·353	14·05		7327	0·369028	40·658	30·71
372	12751	0·399774	26·851	47·23	393	7291	0·281508	13·743	13·48
	12800	0·337053	14·458	02·86		7309	0·383240	48·152	39·35
	12802	0·263173	40·572	26·65		7327	0·335252	40·658	30·71
373	12717	0·410372	01·755	53·88	394	7282	0·257742	36·374	56·30
	12725	0·288624	16·495	59·16		7307	0·431762	41·664	52·42
	12776	0·301004	34·588	16·25		7331	0·310496	17·727	27·11
374	12673	0·396372	58·012	54·53	395	7282	0·283810	36·374	56·30
	12772	0·394610	19·304	40·71		7291	0·384548	13·743	13·38
	12774	0·209017	33·562	48·37		7313	0·331642	21·986	09·95
375	12651	0·366311	30·748	40·90	396	7274	0·364431	24·786	04·98
	12737	0·289130	26·815	53·36		7294	0·324272	39·785	21·44
	12751	0·344559	26·852	47·23		7327	0·311297	40·658	30·71
376	12655	0·280283	55·940	05·09	397	7230	0·316734	41·650	04·56
	12710	0·322774	52·369	36·38		7240	0·300807	36·632	17·02
	12749	0·396944	01·277	44·81		7275	0·382459	34·408	36·97
377	12674	0·462359	02·877	36·99	398	7229	0·338400	25·333	25·02
	12737	0·223866	26·815	53·36		7258	0·473143	38·496	10·02
	12749	0·313775	01·277	44·81		7270	0·188457	09·018	38·26
378	12658	0·322946	03·473	16·52	399	7131	0·325125	58·063	58·35
	12667	0·277180	35·785	22·34		7167	0·270830	00·030	02·43
	12774	0·399874	33·562	48·37		7139	0·404045	11·059	34·31
379	12667	0·246837	35·785	22·34	400	7116	0·298485	46·307	56·20
	12748	0·363331	03·187	29·81		7145	0·487358	35·900	38·84
	12749	0·389832	01·277	44·81		7199	0·214157	12·080	36·91
380	12688	0·295690	58·560	32·79	401	7062	0·405496	39·199	43·45
	12730	0·511406	48·302	51·62		7088	0·279570	06·708	58·56
	12774	0·192903	33·562	48·37		7092	0·314934	50·332	08·30
381	12737	0·317366	26·815	53·36	402	7071	0·439138	21·487	10·82
	12802	0·316774	40·572	26·65		7086	0·396272	45·628	34·42
	12807	0·365860	04·900	12·02		7096	0·164590	22·516	17·99
382	12730	0·328594	48·302	51·62	403	7027	0·320240	12·228	45·86
	12789	0·409512	51·478	29·80		7029	0·360266	18·106	07·62
	12837	0·261895	34·545	36·41		7061	0·319494	38·200	44·16
383	12789	0·314016	51·478	29·80	404	7036	0·467058	52·165	06·23
	12802	0·335012	40·572	26·65		7041	0·256163	08·204	03·91
	12887	0·350972	43·803	58·63		7053	0·276779	41·261	26·69
384	12774	0·302890	33·562	48·37	405	6996	0·216336	36·044	09·77
	12868	0·365408	31·246	37·82		7006	0·461635	44·869	44·48
	12011	0·331702	53·450	26·89		7036	0·322029	52·165	06·23
385	7100	0·291340	27·057	34·34	406	6987	0·300446	20·197	23·47
	7134	0·270766	24·840	09·24		7018	0·263475	21·354	05·41
	7145	0·437894	35·901	38·84		7024	0·436080	06·875	17·39
386	7107	0·202668	49·789	59·38	407	7442	0·330489	44·929	26·25
	7139	0·232083	11·059	34·29		7460	0·285390	18·570	50·26
	7131	0·565249	58·064	58·35		7471	0·384121	38·775	08·83
387	7151	0·233582	27·137	26·19	408	6952	0·206323	37·349	34·33
	7176	0·389754	11·833	37·82		7454	0·501146	25·480	12·45
	7199	0·376663	12·080	36·91		7483	0·292531	52·580	22·92

TABLE II—*continued*

No.	Star	Depend.	R.A. s	Dec. "	No.	Star	Depend.	R.A. s	Dec. "
409	7420	0·371022	32·369	14·61	414	7386	0·373677	04·540	02·73
	7449	0·285630	42·697	23·12		7444	0·276471	03·332	47·27
	7451	0·343348	10·954	44·03		8467	0·349852	24·467	05·02
410	7428	0·413678	33·260	04·80	415	8566	0·370026	50·747	51·80
	7429	0·294778	46·669	12·69		8603	0·263950	54·944	51·97
	7461	0·291544	24·290	32·33		8580	0·366024	48·011	47·16
411	7386	0·284266	04·539	02·73	416	8552	0·294355	44·631	06·68
	7428	0·318222	33·260	04·80		8594	0·447984	50·555	37·90
	7434	0·397512	50·182	14·45		8588	0·257661	58·567	48·37
412	7398	0·388929	56·494	03·18	417	8612	0·277510	53·869	17·63
	7423	0·316983	58·706	21·77		8625	0·366972	51·682	07·36
	7449	0·294088	42·698	23·11		8651	0·355518	41·904	40·26
413	8441	0·278822	13·123	19·25	418	8607	0·266868	33·625	12·83
	7414	0·406438	14·890	06·48		8636	0·422714	25·841	16·55
	7445	0·314741	07·749	16·32		8642	0·310419	20·032	17·55

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Conditions for Stability in Chain Reactions

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ABSTRACT—The conditions for stability in chain reactions in 1, 2 and 3 dimensions have been investigated. In each case a critical maximum size of the vessel has been found, beyond which no steady state is possible.

1. Introduction

In a previous paper (Bosworth and Groden, 1960) the propagation of a chain mechanism through a reacting system with only first order initiation and termination processes was investigated in cylindrical and spherical co-ordinates approximating to the conditions in long cylindrical and spherical reactors respectively. In the following paper, conditions for the existence of the steady state are analysed and an important extension to a reactor in the form of a spherical shell fully investigated.

2. Steady State Conditions

The propagation of a chain mechanism through a reacting system with only linear branching and rupture in the bulk phase is represented by the differential equation

∂N/∂t=A+BN+D∇²N (1)

where N is the concentration of active centres ;

A represents the total initial rate of formation of centres and is always positive ;

BN is the net difference between linear branching and linear homogeneous termination ; the factor B accordingly can be positive, negative, or in exceptional cases zero ;

D is the mean coefficient of diffusion of the centres through the reaction mixture and is always positive.

Assuming circular and spherical symmetry respectively, the following results were obtained : (a) for a cylinder of radius R, where r is the distance from its axis, when B>0 (excess of branching over rupture in the volume)

N(r,t)=a²/b² [J₀(b/d r) / J₀(b/d R) - 1] - 2a² / R ∑_{k=1}^∞ [J₀(λ_k r) · e^{-t[d²λ_k²-b²]} / λ_k · J₁(λ_k R) · (d²λ_k²-b²)] (2)

where

A=a², B=b², D=d²,

J₀ and J₁ are Bessel functions of the first kind of order zero and order one respectively, and λ_k are the roots of the equation

J₀(λ_k R)=0 (3)

(Carslaw, 1948, pages 123/4) ;

(b) for a sphere of radius R, where r is the distance from the origin, when B>0

N(r,t)=a²/b² [R sin(b/d r) / r sin(b/d R) - 1] + 2a²d²/δ · 1/r ∑_{k=1}^∞ (-1)ᵏ [sin k(δ/d r) / k[δ²k²-b²] e^{-t[δ²k²-b²]}] (4)

where

δ=πd/R (5)

If now $t \rightarrow \infty$, it follows from (2) that a steady state exists only if the coefficient of (t) in the exponent is negative, i.e., if

$$d^2\lambda_k^2 - b^2 > 0$$

or

$$\lambda_k > \left| \frac{b}{d} \right|$$

Since λ_k , the roots of the eqn. (3), form a sequence of increasing numbers, it is sufficient if

$$\lambda_1 > \frac{b}{d}$$

or

$$\frac{2 \cdot 4}{R} > \frac{b}{d} = \sqrt{\frac{B}{D}}$$

This is true if

$$R < 2 \cdot 4 \sqrt{\frac{D}{B}} \quad \dots \dots \dots (6)$$

Similarly, we find from eqns. (4) and (5) that a steady state exists only if

$$R < \pi \sqrt{D/B} \quad \dots \dots \dots (7)$$

It appears, therefore, that for both vessels there exists for each reaction with $B > 0$ a *critical maximum size* of the vessel beyond which no steady state is possible.

It is very well known that gaseous systems involving chain mechanisms, such as those of hydrogen and oxygen or chlorine, will lead to an explosion at a critical pressure—or at a critical value of B for a fixed value of R . The theory, however, as at present given in this paper, goes further and states that the anticipated critical density at a fixed radius or critical radius at a fixed density will be different in spherical as compared to long cylindrical bodies in a fixed ratio of π to λ_1 and this is a matter which can and will be tested by experimental means.

At present, experiments are being devised for the empirical determination of this critical value of R which then could be used for estimation of the constant B .

3. Concentration in a Spherical Shell

Of some practical importance is the case in which reaction takes place in a spherical shell bounded by 2 concentric spheres of radii R_1 and $R_2 > R_1$, respectively.

The problem is to find a solution of equation (1) in spherical co-ordinates, subject to the boundary conditions

(a) $n=0$ when $t=0$

(b) $n=0$ when $r=R_i$, $i=1, 2$ $t>0$.

Then

$$\nabla^2 N = \frac{\partial^2 N}{\partial r^2} + \frac{2}{r} \frac{\partial N}{\partial r}$$

where r is the distance from the centre and

$$R_1 \leq r \leq R_2$$

and (1) becomes

$$\frac{\partial N}{\partial t} = A + BN + D \left(\frac{\partial^2 N}{\partial r^2} + \frac{2}{r} \frac{\partial N}{\partial r} \right) \quad \dots \dots \dots (8)$$

Putting

$$B = b^2, \quad D = d^2, \quad \dots \dots \dots (9)$$

$$\rho = \frac{b}{d} r, \quad P_i = \frac{b}{d} R_i, \quad i=1, 2, \quad \dots \dots \dots (10)$$

and

$$N=M-\frac{A}{B} \quad \dots\dots\dots (11)$$

we have for $B=b^2>0$:

$$\frac{1}{b^2} \frac{\partial M}{\partial t} = \frac{\partial^2 M}{\partial \rho^2} + \frac{2}{\rho} \frac{\partial M}{\partial \rho} + M \quad \dots\dots\dots (12)$$

The substitution

$$M(\rho, t) = \frac{1}{\rho} \cdot P(\rho, t) \quad \dots\dots\dots (13)$$

reduces (12) to the form

$$\frac{1}{b^2} \frac{\partial P}{\partial t} = \frac{\partial^2 P}{\partial \rho^2} + P \quad \dots\dots\dots (14)$$

Using the method of separation of variables

$$P(\rho, t) = T(t) \cdot Z(\rho) \quad \dots\dots\dots (15)$$

we find that

$$P(\rho, t) = \alpha_0 \cos \rho + \beta_0 \sin \rho + \sum_{k=1}^{\infty} e^{-b^2(\lambda_k^2-1)t} (a_k \cos \lambda_k \rho + b_k \sin \lambda_k \rho) \quad \dots\dots (16)$$

where α_0 , β_0 , λ_k , and a_k and b_k are constant to be determined from the boundary conditions.

Thus, we have that

$$N(\rho, t) = \frac{1}{\rho} [\alpha_0 \cos \rho + \beta_0 \sin \rho] - \frac{A}{B} + \frac{1}{\rho} \sum_{k=1}^{\infty} e^{-b^2(\lambda_k^2-1)t} (a_k \cos \lambda_k \rho + b_k \sin \lambda_k \rho) \quad \dots (17)$$

If now $t=0$, $N=0$ and the last equation yields the result

$$\frac{A}{B} \rho - (\alpha_0 \cos \rho + \beta_0 \sin \rho) = \sum_{k=1}^{\infty} a_k \cos \lambda_k \rho + b_k \sin \lambda_k \rho \quad \dots\dots\dots (18)$$

which is possible only if a_k and b_k are coefficients of the half range Fourier series of the function $\frac{A}{B} \rho - (\alpha_0 \cos \rho + \beta_0 \sin \rho)$ in the half range $P_1 \leq \rho \leq P_2$ with

$$\lambda_k = k \left[\frac{\pi}{P_2 - P_1} \right], \quad k=1, 2 \quad \dots\dots\dots (19)$$

(see Appendix).

The values of α_0 and β_0 can be determined from the condition that $N=0$ when $r=R_i$ or $\rho=P_i$, at any time, and hence, in the steady state, provided it exists.

As $t \rightarrow \infty$, it follows from (17) that a steady state exists only if

$$\lambda_k^2 - 1 > 0 \quad \dots\dots\dots (20)$$

which is satisfied if $\lambda_1 > 1$. This last condition yields in view of (19) the result that

$$P_2 - P_1 < \pi$$

or

$$R_2 - R_1 < \pi \sqrt{\frac{D}{B}} \quad \dots\dots\dots (21)$$

In this case we find that

$$\left. \begin{aligned} \alpha_0 &= \frac{A}{B} \left[\frac{P_1 \sin P_2 - P_2 \sin P_1}{\sin (P_2 - P_1)} \right] \\ \beta_0 &= \frac{A}{B} \left[\frac{P_2 \cos P_1 - P_1 \cos P_2}{\sin (P_2 - P_1)} \right] \end{aligned} \right\} \quad \dots\dots\dots (22)$$

and

so that finally

$$N(\rho, t) = \frac{A}{B} \left[\frac{1}{\rho} \cdot \frac{P_1 \sin(P_2 - \rho) + P_2 \sin(\rho - P_1)}{\sin(P_2 - P_1)} - 1 \right] + \frac{1}{\rho} \sum_{k=1}^{\infty} e^{-b^2(\lambda_k^2 - 1)t} (a_k \cos \lambda_k \rho + b_k \sin \lambda_k \rho) \dots \dots \dots (23)$$

For $P_2 - P_1 < \pi$ the steady state solution is given by the first term of the above equation :

$$N(\rho, t) = \frac{A}{B} \left[\frac{1}{\rho} \cdot \frac{P_1 \sin(P_2 - \rho) + P_2 \sin(\rho - P_1)}{\sin(P_2 - P_1)} - 1 \right] \dots \dots \dots (24)$$

which has its peak value at the distance ρ from the centre where ρ is the solution of the equation

$$\rho = \tan(\rho - \varphi) \dots \dots \dots (25)$$

with

$$\varphi = \tan^{-1} \left[\frac{P_1 \sin P_2 - P_2 \sin P_1}{P_1 \cos P_2 - P_2 \cos P_1} \right] \dots \dots \dots (26)$$

Equation (25) can be solved graphically or by numerical methods.

When $P_1 = 1$ and $P_2 = 2$, we find that $\varphi = 0.48$,

and $\rho = 1.5$ approximately, i.e., near the middle.

For $P_1 = 1$ and $P_2 = 3$, $\varphi = 0.74$ and $\rho = 1.8$ approximately.

If $B < 0$ we have to replace b^2 by $(-b^2)$ in all our equations and we find that

$$N(\rho, t) = \frac{A}{B} \left[1 - \frac{P_1 \sinh(P_2 - \rho) + P_2 \sinh(\rho - P_1)}{\sinh(P_2 - P_1)} \right] + \frac{1}{\rho} \sum_{k=1}^{\infty} e^{-b^2(\lambda_k^2 - 1)t} (a_k \cos \lambda_k \rho + b_k \sin \lambda_k \rho) \dots \dots \dots (27)$$

Here, as $t \rightarrow \infty$, steady state always exists and is given by the first term of equation (27).

In the limiting case where $R_1 \rightarrow 0$, $R_2 = R$, equations (23) and (27) give the same results as those obtained directly in the case of a spherical vessel.

Reaction between concentric spherical shells exhibit the same characteristics as those in spherical bodies ; namely, that if the rate of chain branching exceeds the rate of chain termination there is a certain limiting critical size defined by the difference between the internal and external radii beyond which it is impossible to obtain a steady state solution.

If the rate of termination exceeds the rate of branching, the process is stable in vessels of all sizes.

Under steady state conditions, if obtainable, there is a certain region of the annular vessel in which there occurs the highest concentration of active centres. For vessels in which the external radius is about twice the internal radius, this occurs approximately midway between the two shells. The centre of maximum density, however, moves inwards as the internal radius is made progressively smaller.

4. Concentration between Parallel Plates

To complete the theory, the case of reaction in one dimension (between 2 parallel plates, the distance $2c$ apart) was also investigated.

If x is the distance, measured from the centre ($-c \leq x \leq c$), the following result can be obtained by the use of the method of separation of variables for $B > 0$:

$$N(x, t) = \alpha_0 \sin\left(\frac{b}{d}x\right) + \beta_0 \cos\left(\frac{b}{d}x\right) - \frac{A}{B} + \sum_{k=1}^{\infty} e^{-(d^2\lambda_n^2 - b^2)t} (a_n \cos \lambda_n + b_n \sin \lambda_n t) \dots \dots \dots (28)$$

where

$$\lambda_n = \frac{\pi}{c} n, \quad n=1, 2, \dots \quad (29)$$

and a_n, b_n are coefficients of an appropriate sine and cosine Fourier series in the interval $(-c, c)$.

Here, the steady state exists only if, again,

$$d^2 \lambda_n^2 - b^2 > 0$$

which is satisfied if

$$c < \pi \sqrt{\frac{D}{B}}, \quad \dots \quad (30)$$

a condition identical with that for a sphere.

Then the steady state solution is given by the expression

$$N = \frac{A}{B} \left[\frac{\cos \frac{b}{d} x}{\cos \frac{b}{d} c} - 1 \right] \quad \dots \quad (31)$$

If $B < 0$, steady state always exists.

5. Appendix

(Expansion in a half range sine Fourier series in the interval $P_2 - P_1$)

In order to expand the function

$$f(\rho) = \frac{A}{B} \rho - \alpha_0 \cos \rho - \beta_0 \sin \rho = k_1 \rho + k_2 \cos \rho + k_3 \sin \rho \quad \dots \quad (32)$$

in a half range sine Fourier series in the interval $P_1 \leq \rho \leq P_2$ we use the transformation

$$x = \left(\frac{\rho - P_1}{P_2 - P_1} \right) \pi = \lambda \rho - \lambda P_1 \quad \dots \quad (33)$$

or

$$\rho = \frac{x}{\lambda} + P_1 \quad \dots \quad (34)$$

Then as ρ varies from P_1 to P_2 , x varies from 0 to π . Using (32) and (34) we then have

$$\begin{aligned} f(\rho) \rightarrow g(x) &= k_1 \left(\frac{x}{\lambda} + P_1 \right) + k_2 \cos \left(\frac{x}{\lambda} + P_1 \right) + k_3 \sin \left(\frac{x}{\lambda} + P_1 \right) \\ &= A_0 x + B_0 + C_0 \cos \left(\frac{x}{\lambda} \right) + D_0 \sin \left(\frac{x}{\lambda} \right). \end{aligned}$$

We expand $g(x)$ in a half range sine series in the interval $(0, \pi)$

$$g(x) = \sum_{n=1}^{\infty} C_n \sin (nx) \quad \dots \quad (35)$$

where

$$C_n = \frac{2}{\pi} \int_0^{\pi} g(x) \sin nx dx \quad \dots \quad (36)$$

Therefore

$$g(x) = \sum_{n=1}^{\infty} C_n \sin nx$$

or

$$\begin{aligned} f(\rho) &= \sum_{n=1}^{\infty} C_n \sin n(\lambda\rho - \lambda P_1) \\ &= \sum_{n=1}^{\infty} a_n \cos(n\lambda\rho) + b_n \sin(n\lambda\rho) \end{aligned}$$

or

$$f(\rho) = \sum_{n=1}^{\infty} a_n \cos \lambda_n \rho + b_n \sin \lambda_n \rho \quad \dots\dots\dots (37)$$

where

$$\lambda_n = n\lambda = n \frac{\pi}{P_2 - P_1}, \quad n=1, 2 \quad \dots\dots\dots (38)$$

and

$$\left. \begin{aligned} a_n &= -C_n \cdot \sin \lambda_n P_1 \\ Cn &= C_n \cdot \cos \lambda_n P_1 \end{aligned} \right\} \quad \dots\dots\dots (39)$$

6. References

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A Note on Selective Fracturing in Vitrain

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ABSTRACT—The regularity of the fracturing of the vitrain bands of some Bulli seam coal was observed. Reference is made to the importance of this fracturing with respect to dust formation and selective concentration.

Observations on selective fracturing in vitrain of the Bulli seam were made at a Colliery on the South Coast of New South Wales. The Bulli seam which is at the top of the Upper coal measures is overlain by sandstone, the cover at the area investigated varies from 100 to 1400 feet. The floor is shale and sandstone, and the average seam thickness is six feet six inches. The area is subjected to faults, is intruded by dykes and affected by rolls, elongated sub-parallel ridges in the floor reaching almost to the roof. Slickensides occur, possibly due to differential compaction. At the Colliery investigated, the bord and pillar method of mining is practised, continuous miners being used.

The coal is ortho-bituminous. Examination of pillar samples showed 18·9 per cent vitrain, 80·8 per cent claro-durain and 0·3 per cent shale. The vitrain is composed almost entirely of vitrinite and contains a small proportion of spores and fine mineral matter. The bands of vitrain vary in thickness from $\frac{1}{16}$ to $\frac{1}{2}$ inch.

The bands of clarain contain macro and micro spores, cuticles and heterogenously disseminated mineral matter, with shreds of vitrite. Fusinite occurs as small blebs and although a few large sections were observed the total quantity is small. All mineral matter appeared as free, fine grains, no sulphides or precipitated salts were observed.

The vitrain bands are very fractured and this is associated with the observed tendency of the coal to breakage, producing much fine material. The fine coal from this seam is therefore rich in bright coal constituents, indicating the possibility of selective concentration. It was possible to obtain samples of each coal constituent and their compositions are compared with a dust sample from the mine (Table I).

These results and a maceral analysis of the dust indicated that vitrain forms an important percentage of the mine dust.

Further examination showed that the vitrain is so fractured that when the large coal is broken a high proportion of vitrain is liberated as fines and dust, while the remainder is firmly adherent to the adjacent clarain; but exhibits a prominent cleavage most pronounced in one direction and less so in another direction at approximately 70° to the first (see Plate I).

An examination of polished sections clearly showed the fracture patterns in the vitrain (Plate I). This phenomenon was not apparent in the other coal constituents.

TABLE I

Comparison of the composition of the dust with the coal constituents of the seam

Per cent (air dried basis)					
		Moisture	Volatile	Fixed Carbon	Ash
Mine dust	..	2·0	24·5	62·1	11·3
Fusain	..	0·4	0·4	88·8	10·4
Clarain	..	1·2	17·0	68·9	12·8
Vitrain	..	1·2	25·4	71·8	1·5

A survey of the mine from which the samples were obtained showed that all the vitrain exhibits the same fracture pattern. The strike of the fracture plane was measured in many sections of the mine and was found to be in a North-South direction with minor variations between $\pm 5^\circ$. Although the direction of the strike was constant the inclination of these fractures in the vitrain bands varied from vertical at the shaft bottom to 60° to the plane of lamination three miles in by.

The direction of the strike is the same as the direction of the cleat in the coals of the Northern Hemisphere, while the angle of inclination of these fractures is similar to the angle of the slips and backs which are often well developed especially in the anthracitic coals of Wales.

Possibly the cause of these fractures was the action of tectonic forces, resulting from the rapid variation in the depth of cover and the existence of mechanically weak clay bands which have permitted the whole to move towards the East with resultant land slides. These forces have been transmitted to the coal seam with the weakest section, the brittle vitrain bands fracturing. The operations of mining have produced further fracturing along the pre-determined planes.

Water infusion into the coal seam was successful in pillar coal but not in the solid coal. This supported the observation that the fracturing is confined to the vitrain bands and the claro-durain is not fractured until the coal is subjected to further stress.

Samples of the coal fines from the operating faces in the mine were beneficiated by froth flotation using kerosene and eucalyptus oil as reagents. Results are shown in Table II.

These results showed that a high grade concentrate with a high recovery was possible since the coal fines contain a high percentage of free vitrain which has a low ash content.

TABLE II
Beneficiation of coal fines by froth flotation

	Wt. %	Ash %	Recovery %	
			Coal	Ash
Feed	100	8.0		
Concentrate ..	88.3	4.0	92.1	43.9
Middlings ..	4.3	22.2	3.6	11.7
Reject	7.4	47.9	4.3	44.4

However, the aerophilic properties of the surface of the fine coal particles makes dust suppression by water sprays difficult and dust suppression in mines working this seam remains a problem.

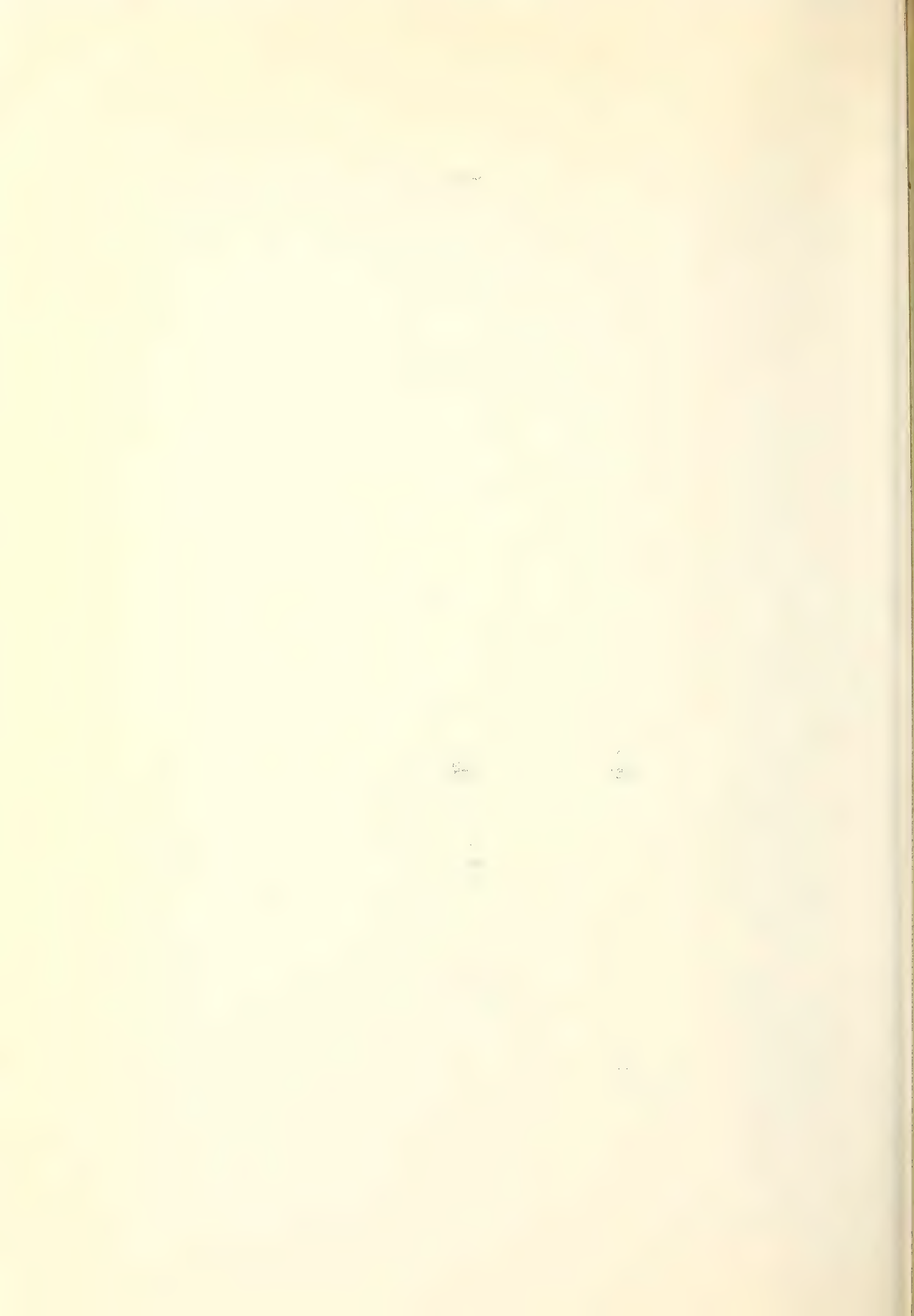
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Coal from the Bulli seam showing the fracture pattern in the vitrain. Samples $\times 1$, photomicrographs $\times 80$

Explanation





Geology of the Bulahdelah - Port Stephens District, N.S.W.

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ABSTRACT—The stratigraphic sequence of the Bulahdelah-Port Stephens district is defined and described. New formational subdivisions are related to existing terminology.

The oldest strata present are the Wootton Beds, the base of which has not been observed. They are overlaid conformably by the following sequence of Carboniferous formations: Conger Formation, Nerong Volcanics, Crawford Formation, Alum Mountain Volcanics, and by the Permian Formations: Markwell Coal Measures, Bulahdelah Formation.

The Carboniferous sedimentary sequences are composed largely of lithic arenites together with lesser amounts of conglomerate and friable and indurated mudstones. Interbedded volcanic flows vary in composition from rhyolite to basalt.

Stratigraphical mapping was based upon the presence of several important palaeontological zones which include the following: Wootton Beds—Lower Burindi Series faunas closely comparable with those of Campbell (1956, 1957) and Cvacara (1958). Crawford Formation—(i) *Margini-rugus barringtonensis* zone, (ii) Pelecypod zone (Voisey, 1940), (iii) *Thamnopora* zone, and (iv) *Levipustula* zone.

Introduction

This paper embodies the results of a stratigraphical study of the area covered by the Bulahdelah, Port Stephens, Seal Rocks and Morna Point One-Mile Military Maps.

Outcrops are chiefly Carboniferous strata; some Permian formations are preserved in the Myall Syncline. Each of the four "series" previously used in classifying the Carboniferous in New South Wales was formerly thought to be represented in the area and stratigraphical re-examination was directed especially towards elucidating facies relationships and investigating the existence and correlation of units regarded as marine and terrestrial.

Throughout the text, grid references have been given to localities with the following abbreviations for the One-Mile Military Sheets: Bulahdelah (B.), Seal Rocks (S.R.), Krambach (K.), Port Stephens (P.S.), and Morna Point (M.P.).

Previous Literature

Port Stephens Area—The study of the geology of the Port Stephens district extends back into the 19th century when Odenheimer and Herbon (1855-7) prepared a series of reports and maps for the Australian Agricultural Company. In 1907, David completed his Memoir upon the Coal Measures of the Hunter Valley, the maps of which extend into the Port Stephens area. Brief reference was made to the Carboniferous strata of that area. Subsequently, three papers have appeared dealing with this area. The first was by Sussmilch and David (1919) dealing with general aspects of the stratigraphy of the

Carboniferous, the second was by Sussmilch and Clarke (1928) describing the geology and petrology of the Port Stephens area and the third was a recent paper by Nashar and Catlin (1959) upon the nature and occurrence of basalt dykes in the Port Stephens region.

Bulahdelah Area—In this northern sector, very little stratigraphical investigation has ever been carried out. The Bulahdelah Alunite deposit has attracted attention since its discovery in 1890. Descriptions are given by Pittman (1901), Harper (1923, 1924, 1928), Booker (1940), Osborne (1950) and in the Annual Reports of the Department of Mines, N.S.W.

The first attempt at general reconnaissance mapping was carried out by Carey (1934) in the Myall Lakes region. Subsequent to this, Voisey (1940) commenced a study of the district between the Manning and Karuah Rivers but only a summary of the information gathered was published.

In 1950 Osborne published his structural study of the Hunter-Manning-Myall Province but unfortunately most of the stratigraphy of the Myall region on which this structural mapping was based has not been published.

Physiography

Relief is mainly controlled by folds which trend from due north to N 40° W and by associated faults.

The area of highest relief is situated in the northwest portion of the map where the maximum physiographical level (2100 ft.) coincides with the Crawford Anticline. To the

south, in the axial portion of the Girvan Anticline, this level falls to an average of 400 ft. whilst to the east, a sharp drop in elevation to 0–200 ft. marks the site of the Myall Syncline, the physiographical valley of the Myall River. East of Bulahdelah, resistant strike ridges rise to just over 1000 ft. in elevation, being separated, particularly in the area of the Bungwahl Anticline, by regions where the level drops to an average of 300 ft.

The Crawford Anticline and associated fault structures are drained by the south-flowing Crawford River which joins the Myall River near Bulahdelah. The floor of the Myall River valley is a flat alluvial plain in which the river meanders its way south to Broadwater Lake. The outlet to this lake, also called the Myall River, becomes confined at Tamboy (321748 P.S.) and from here runs approximately south to connect with Port Stephens. The region south of the Bulahdelah-Booral road is drained by the Karuah River and its tributaries which also flow into Port Stephens.

Drainage on the eastern side of the Myall Syncline is either by south-flowing creeks such as Boolambayte Creek or by north-flowing streams such as Coolongolook and Wallingat Rivers. Much of the drainage pattern in this area is controlled by the development of strike ridges.

Port Stephens is a drowned river valley, extending 13 miles in an east-west direction. The maximum width of 5 miles is reduced to one-quarter of a mile at Soldier's Point (093568 P.S.) where a resistant toscanite ridge crosses the harbour, almost cutting it into two parts.

The remainder of the coastal belt is occupied by extensive brackish lakes separated by large areas of low lying sand dunes and mudflats.

Review of Stratigraphical Terminology

CORRELATION OF CARBONIFEROUS FORMATIONS

The Bulahdelah region was previously considered by Osborne (1950) to contain (a) laterally constant facies of the marine Lower Burindi Series and of the clastic, glacial and volcanic Upper Kuttung Series, and (b) in the Myall Syncline, a concealed lateral transition from terrestrial and volcanic Lower Kuttung Series on the western limb to marine sediments of the Upper Burindi Series on the eastern limb.

(A) "*Lower Burindi Series*"—The beds previously referred to this Series in the Bulahdelah region differ notably from the type Burindi Series (Benson, 1913) in both lithology and

TABLE I

Carboniferous Stratigraphic Subdivisions used by Osborne (1950) for the Bulahdelah Region

<i>Western limb of Myall Syncline</i>	<i>Eastern Limb of Myall Syncline</i>
Upper Kuttung Series	Upper Kuttung Series
Lower Kuttung Series	Upper Burindi Series
Lower Burindi Series	Lower Burindi Series

thickness. Whereas the rocks of the type area consist predominantly of friable olive-green mudstones with bands of 'tuff', the facies developed in this coastal region is dominated by lithic arenites ('tuffs' of Voisey, 1940) with subordinate amounts of indurated and friable mudstones. This lithological change is coupled with an enormous thickening of up to approximately 40,000 ft. Therefore, the term Wootton Beds, in lieu of "Lower Burindi Series", is proposed for this area.

The fossil content of the Wootton Beds is rather limited but enough is known of the fauna to establish partial time-rock equivalence with the Lower Burindi Series.

(B) "*Lower Kuttung Series—Upper Burindi Series*"—Contrary to the statements of previous authors, the sequences on either side of the Myall Syncline have been found to be essentially similar, hence the above alternative nomenclature is unnecessary.

The term "Kuttung Series", as defined by Sussmilch and David (1919) and as amended by Osborne (1922 et seq.) and Carey and Browne (1938), has been used by previous authors to refer to the sequence on the western limb of the Myall Syncline. On that limb, the Wootton Beds are followed by the Conger Formation and the Nerong Volcanics, both of which are defined below. Osborne (1950) placed this portion of the sequence in the Basal and Volcanic Stages of the Lower Kuttung Series. This naming has been discontinued because (a) the Conger Formation is clearly of marine origin in contrast with the terrestrial nature of the "Basal Stage" in its type area and (b) the Nerong Volcanics contain far less lithological variants than does the type "Volcanic Stage".

On the eastern limb, above the Wootton Beds, there is a thin sequence of dacite flows (50–100 ft.) followed by fossiliferous beds previously known as the "Upper Burindi Series". This marine sequence was separated arbitrarily from the overlying, essentially similar "Upper Kuttung Series" (Voisey, 1940), there being no lithological break in the sequence. It is herein contended that in this limb there is no develop-

ment of the Conger Formation and that the Wootton Beds are succeeded by dacite flows which represent the Nerong Volcanics. Therefore, all the overlying sediments will belong to another formation, defined below as the Crawford Formation, which is developed on both sides of the fold axis. This conclusion is supported by the fauna of that formation.

(C) "*Upper Kuttung Series*"—On the western limb, above the Nerong Volcanics, Osborne (1950) thought he recognized rocks of the Upper Kuttung Series consisting of a lower 'Main Clastic Zone' and an upper volcanic sequence. From his description it is clear that no glacial sediments were found in this area, hence the term 'Glacial Stage' was not used.

It is now established that the 'Main Clastic Zone' is of marine origin for it contains an abundance of marine fossils in this district (see Text-Figure 3). On these grounds it is no longer correct to use the term Upper Kuttung Series since this applies to the terrestrial sequence of the Clarencetown-Paterson-Seaham area.

A notable occurrence is that of *Marginirugus barringtonensis* (Dun), an index fossil for the Upper Burindi Series which has been found on both sides of the syncline. On the western limb it occurs in the basal beds of the so-called "Upper Kuttung Series" ('Main Clastic Zone'), above the Nerong Volcanics. Similarly in the eastern limb it occurs in sediments immediately above dacite flows in the "Upper Burindi Series". On the grounds of the lithological and palaeontological similarity, it is proposed to abandon the supposed equivalence of the local representatives of the "Lower Kuttung Series-Upper Burindi Series", and in their place substitute the term Crawford Formation to describe all sediments above the volcanic flows on either side of the syncline.

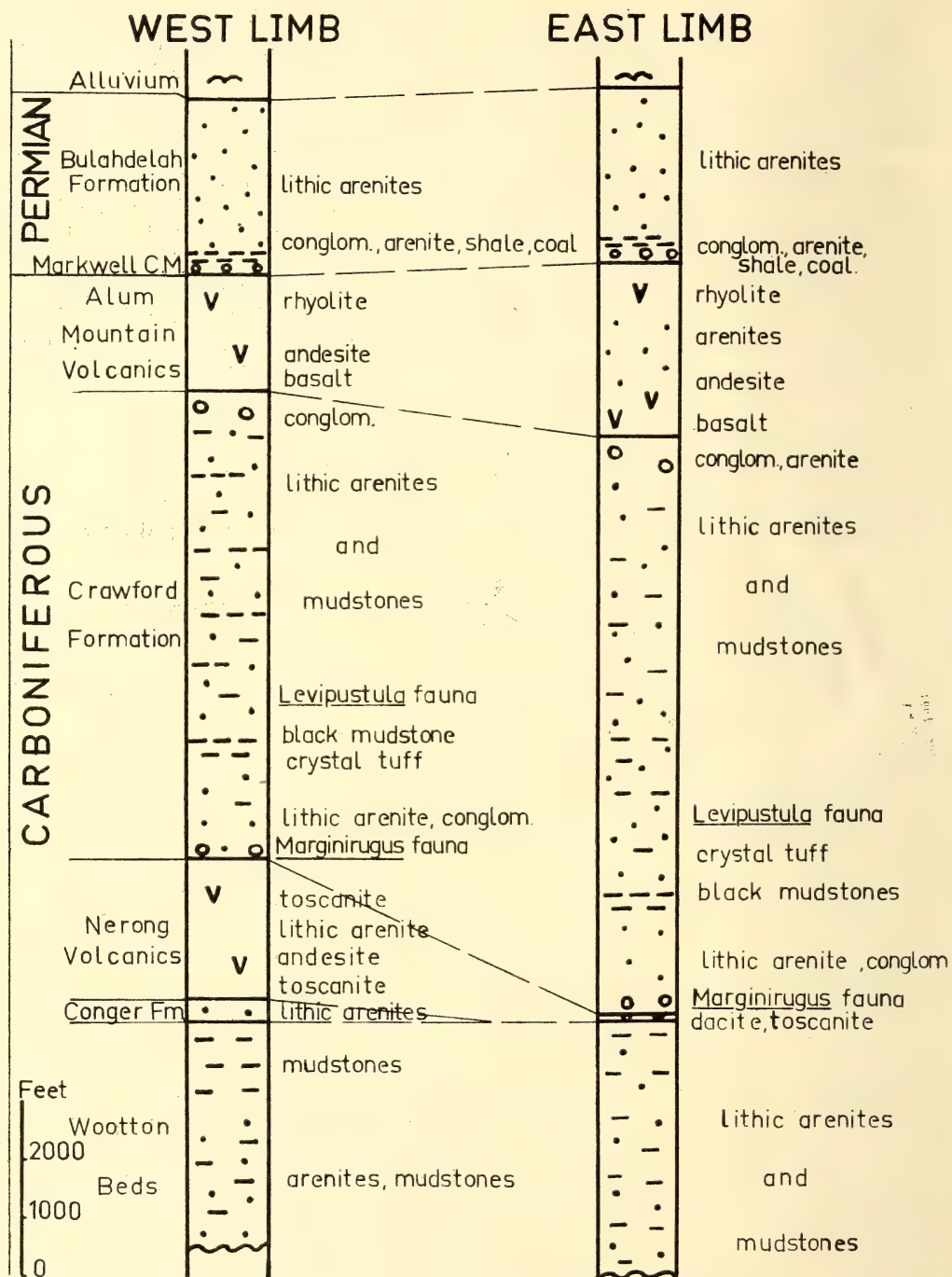
It is of importance to note that there are no deposits in this area which have been formed as a result of direct glacial action.

On both limbs of the Myall Syncline, the Crawford Formation is capped by volcanic flows

TABLE II

Relationship between former and newly adopted Carboniferous nomenclature for the Bulahdelah region. (---?---?---?=undefined boundary; -----= new correlation)

New Nomenclature	Osborne, 1950			
	West of Myall Syncline		East of Myall Syncline	
Alum Mountain Volcanics	Upper Kuttung Series	Volcanic Flows	Upper Kuttung Series	Volcanic Flows
Crawford Formation		Main Clastic Zone		Main Clastic Zone
Nerong Volcanics		Volcanic Stage	Upper Burindi Series	---?---? Clastic Sediments
Conger Formation	Lower Kuttung Series	Basal Stage		Volcanic flows
Wootton Beds	Lower Burindi Series		Lower Burindi Series	



TEXT-FIGURE 1

Comparative columnar sections for the east and west limbs of the Myall Syncline

previously placed at the top of the "Upper Kuttung Series" and herein named the Alum Mountain Volcanics.

CORRELATION OF PERMIAN FORMATIONS

The two Permian formations herein recognized were referred by Osborne to the Greta Coal Measures and the Upper Marine Series. The evidence for this correlation is tenuous and it is preferable to refer to them as independent formations—the Markwell Coal Measures and the Bulahdelah Formation. Should Osborne's correlation be correct, there must be a considerable disconformity at the base of the Markwell Coal Measures. The present work suggests that this is unlikely.

Definitive and Descriptive Stratigraphy Wootton Beds

DEFINITION

Synonymy—Lower Burindi Series (Carey, 1934 ; Voisey, 1940 ; Osborne, 1950).

Derivation—Wootton Village (388055 B.).

Representative Sections—Road cuttings from Elizabeth Bay (583012 S.R.) to Hewitt's Lookout (342930 B.) and along the Pacific Highway from north of Coolongolook (366176 K.) to O'Sullivan's Gap (304107 B.).

Lithology—Predominantly grey to brown lithic arenites interbedded with olive-green to brown friable, and black indurated, mudstones. Several conglomerates and one limestone bed are developed within the sequence.

Thickness—Carey (1934) estimated the thickness to be 25,000 ft. At present over 40,000 ft. have been measured in the region to the east of Bulahdelah but this figure is suspect due to the possibility of undetected repetition of beds by strike faulting. One section from Wootton to O'Sullivan's Gap is unfaulted and it contains at least 15,000 ft. of sediments.

Age and Relations—Lower Carboniferous. The base of the Beds has not been examined but in the region to the north, Osborne (1950) considered the contact with Barraba Series mudstones to be a conformable one. The overlying Conger Formation is also conformable.

DESCRIPTION

The Wootton Beds do not contain any distinctive lithological units of sufficient continuity either to permit formational subdivision or to demonstrate the probable presence of repetition of beds by strike faulting.

The dominant lithological type is the hard, bluish coloured lithic arenite which decomposes

to a buff coloured friable rock. The grainsize is irregular being composed of angular mineral and rock fragments, up to 2 mm. in size, set in a finely divided quartzo-feldspathic matrix which is almost impossible to separate from some of the devitrified rock fragments. Mineral fragments consist principally of kaolinized feldspar (commonly andesine) and quartz, showing resorption, together with lesser amounts of biotite, chlorite and various iron minerals.

With gradual decrease in grainsize the arenites grade into indurated, dark coloured mudstones which are of common occurrence. The remainder of the sequence is composed of friable, olive-green to brown, mudstones of similar lithology to that developed in the type Burindi Series.

Sedimentary structures are poorly developed in the Wootton Beds. Some graded bedding and plain cross bedded laminations can be observed on the eastern slope of Hewitt's Lookout. In some regions there is a regular alternation of arenite beds (2–6 ft.) with mudstones (2 ft. and less).

(i) *Section from Elizabeth Bay to Hewitt's Lookout*—The lowest beds examined commence at Charlotte Head (597006 S.R.) as massive conglomerates interbedded with lithic arenites, indurated mudstones and strongly laminated shales. These beds appear to be dislocated structurally from the main outcrop.

From Booti Hill south to Smith Lake, the sequence is composed of indurated and friable mudstones, coarse arenites and a few conglomerate lenses all of which show contemporaneous deformational structures such as folding, contortion and truncation. An unidentified spiriferid fauna occurs at the northern end of Booti Hill (M36-557034 S.R.) and a bed containing fragmental pelecypod shells is exposed at Boomerang Point (M35-586988 S.R.).

Sediments in the region from Smith Lake to Bungwahl consist of west dipping, black, indurated mudstones interbedded with coarse, medium and fine grained lithic arenites. Exposures of friable grey mudstones become common near the township of Bungwahl, where they are poorly fossiliferous (M6-482943 B.). Immediately west of this township, a coarse dacitic conglomerate is followed by fine grained arenites which dip to the east. This reversal of dip is quite sharp, pointing to the presence of a fault rather than to the possibility of folding.

The Bungwahl Anticline is crossed from Bungwahl to the eastern foot of Hewitt's

Lookout (358934 B.), the axis which trends N 40° W being situated near Boolambayte Hill. All the strata dip at a low angle of less than 25°. Rocks exposed are mainly olive-green to grey friable mudstones.

At the eastern foot of Hewitt's Lookout the dip changes from 25° W to 65° W, the exposures being too poor to show the faulting which is presumed to have caused this change. The section exposed up to the crest of the Lookout is an excellent one composed predominantly of lithic arenites together with banded shales, grey-blue mudstones, dark fissile mudstones and fine conglomerates. The arenites show traces of both graded and current bedding, some beds also being very strongly marked by spheroidal weathering. The mudstones are highly carbonaceous in some places. Conglomerate first appears as very thin pebbly bands passing upwards into coarser and thicker beds until full conglomeratic members are encountered.

Just below the eastern crest of the Lookout, a dacite flow of the Nerong Volcanics conformably overlies the Wootton Beds.

(ii) *Myall Lake District*—Around the shores of the lake there are many exposures of the Wootton Beds. Rock types are mainly lithic arenites with minor conglomerates and mudstones. Isolated outcrops of a keratophyre occur near Burrah Burrah Point. A limestone unit is developed at Bibby Harbour (445878 B.) and Mayer's Flat (Carne and Jones, 1919). At the latter locality, the limestone bed is 40–50 ft. thick and can be traced along strike for about 400 ft. It is a coarsely crystalline variety, being overlain by a thin development of impure limestone and calcareous shales. The unit is interbedded with arenites and shales which dip S 70° W at 42°.

On the western side of Bibby Harbour there is a very similar limestone bed 15 ft. thick and also capped by impure limestones and calcareous shales. It has a very low dip and because of its close similarity is thought to be a continuation of the Mayer's Flat horizon. Both areas have been quarried for commercial purposes.

(iii) *Section from Coolongolook to O'Sullivan's Gap*—This section (B–F) commences on Brearick Range 1½ miles north of Coolongolook, where lithic arenites are interbedded with both friable and indurated mudstones. One bed of indurated mudstone contains a profusion of crinoid stems with other fragmental fossiliferous material (M30-366176 K.). From the foot of this range south to Wootton most of the beds are poorly

exposed, friable mudstones, with some thin beds of lithic arenite developed between the Coolongolook River crossing (364085 B.) and Wootton.

At Wootton, the headwaters of the Coolongolook River separate areas of rock with markedly different dip. On the northern side of the river the average dip of 50° W flattens out to 15° W. On the southern side the beds are vertical or even overturned. It is postulated that this anomaly is due to strike faulting, which also is partly responsible for the non-appearance of the Bungwahl Anticline in this region.—It is also possible that this fault is linked with the structural change at the eastern foot of Hewitt's Lookout range.

From Wootton to the eastern foot of O'Sullivan's Gap, mudstones are exposed in road cuttings and the dip gradually changes from vertical to an average of 60° W. Most of the outcrops show strongly developed cleavage.

The sequence exposed on O'Sullivan's Gap range consists mainly of massive lithic arenites with indurated and friable mudstones and minor amounts of conglomerate. The arenite beds vary in thickness from 9 in. to 4 ft. and rarely show any internal stratification. Similar rocks are exposed on the western slopes of the range until a dacite lava flow of the Nerong Volcanics is encountered (Voisey, 1940).

At the western foot of O'Sullivan's Gap, two east-trending transcurrent faults have dislocated a block westwards into the Myall Syncline. The evidence for this faulting is stratigraphic, there being a similar sequence in this block to that already described. Extension of this faulting has not been observed west of the Myall Syncline axis.

(iv) *The Girvan Anticline*—The sequence in this fold is well exposed along the Booral-Bulahdelah road. The western limb is composed predominantly of friable mudstones with lesser development of lithic arenites and conglomerates. Outcrops in the vicinity of Rose Hill are the typical olive-green mudstone which contains a fauna of *Brachythyris* cf. *pseudovalis* Campbell, *Spirifer* cf. *livellus* Cvancara, *Goniocladia* sp., an unidentified trilobite and various fragments of a solitary coral (M8-058836 B.). In this region the Beds are conformably followed by the Conger Formation.

The eastern limb, of similar lithology, also contains brachiopod faunas in its upper portion, namely at (M29-141860 B.) and (M31-146858 B.). Sediments at locality M29 contain *Dictyoclostus*

cf. *simplex* Campbell, *Megachonetes* sp., *Spirifer* sp., *Brachythyris pseudovalis* and *Fluctuaria* sp. Sediments at locality M31 contain *Schizophoria* sp., *Leptagonia* sp., *Pustula abbotti* Campbell, *Daviesiella* cf. *aspinosa* (Dun), *Werriera* cf. *australis* Campbell, *Phricodothyris uniplicata* Campbell, *Spirifer lirellus* and *Brachythyris pseudovalis*. The beds of this limb are more steeply dipping than those of the western side and the contact with overlying formations is faulted.

Several fossil localities have been found in the district south of the Booral-Bulahdelah road (M13-156635 P.S.; M25-168647 P.S.). Locality M13 has yielded *Schizophoria* sp., *Rhipidomella australis*, *Cleiothyridina* sp., *Dictyoclostus* sp., *Brachythyris davidii*, *Phricodothyris* sp., and *Goniocladia* sp. Fossils found at locality M25 include *Schizophoria* sp., *Rhipidomella australis*, *Leptagonia* sp., *Streptorhynchus* sp., *Dictyoclostus* cf. *paradoxus*, *Dictyoclostus* n.sp. (large form), *Spirifer* cf. *lirellus*, *Punctospirifer* sp. and "*Phillipsia*" *collensi* Mitchell.

On the Tea Gardens-Karuah road, the fold becomes poorly defined due to plunging of the axis to the south. Lithology is essentially the same as above. Fragments of *Lepidodendron veltheimianum* occur in some of the lithic arenites.

(v) *Upper Crawford River District*—On the western side of the Crawford River near its headwaters, a sequence of friable olive-green mudstones with small arenite bands underlies the Nerong Volcanics without the development of the Conger Formation which probably was not developed in this area. These sediments are placed in the Wootton Beds on the basis of their lithology and stratigraphic relationships.

Conger Formation

DEFINITION

Synonymy—Lower Kuttung Series (Basal Stage) (Osborne, 1950).

Conger Formation (Campbell, 1959, 1961).

Derivation—Conger Hill (045834 B.).

Type Section—The Branch Road due south from Conger Hill for approximately one and a half miles.

Lithology—Chiefly lithic arenites of grey colour (weathering brown) with lenticular conglomerates.

Thickness—Maximum observed thickness 1200 ft. in the type section, thinning to nil eastwards.

Age and Relations—Lower Carboniferous (Visean?). The formation follows without apparent break upon Wootton Beds and is conformably overlaid by lava flows of the Nerong Volcanics.

DESCRIPTION

Outcrops on the Branch Road reveal lithic arenites and conglomerates which are also found on the track up to Gundaine Trig. (032798 B.) where overlying lava flows occur. The arenites are commonly found in beds from 1 ft. up to 6 ft. in thickness, and they often show well developed current bedding.

At Sagger's Creek, along the Upper Crawford River-Stroud road, comparable arenites (some salmon pink in colour) and conglomerates occur beneath the Nerong Volcanics. The formation is not developed in the Crawford River Fault block beneath the Nerong Volcanics.

Conglomerates and arenites underlie Nerong Volcanics on the Tea Gardens-Karuah road at Bulga Creek (067647 P.S.). The boulders and pebbles are mainly volcanic rocks, including a large percentage of pitchstone boulders, which have an average diameter of 2 to 3 inches but ranging up to 12 inches.

The only occurrence of this formation on the eastern side of the Girvan Anticline is at the western foot of Bulahdelah Mountain on the Booral-Bulahdelah road. At this point Wootton Beds are in faulted contact with coarse conglomerates and arenites which are overlain by Nerong Volcanics. The faulting has produced such intense contortion and dislocation of beds that it is difficult to estimate the thickness. It is suggested that there is not more than 400 ft. exposed in the present outcrop.

The formation is not developed on the eastern side of the Myall Syncline.

Nerong Volcanics

DEFINITION

Synonymy—Lower Kuttung Series (Volcanic Stage) (Osborne, 1950).

Derivation—Nerong Trigonometrical Station (195813 P.S.).

Type Section—Nerong Forestry Road cuttings between (152862 B.) and (160871 B.).

Lithology—Toscanite, dacite, hornblende andesite with minor amounts of ignimbrite, conglomerate and arenite.

Thickness—The type section has a thickness of 2400 ft., which diminishes rapidly to the north and to the east to as low as 50 ft.

Age and Relations—Lower Carboniferous. The formation is conformable with both the underlying Conger Formation and the overlying Crawford Formation.

DESCRIPTION

(i) *Western Limb of the Girvan Anticline*—Physiographically prominent exposures of volcanic rocks mark the region between the Girvan Anticline and the Stroud-Gloucester Syncline.

On the Crawford River-Stroud road, the formation commences with a keratophyre at Sagger's Creek (031011 B.) on the western edge of the present map. The thickness of the formation in this area is about 100 to 200 ft.

In the vicinity of the Branch road on the Booral-Bulahdelah road and extending north towards Sagger's Creek, the Conger Formation is succeeded by flows of keratophyre, toscanite, andesite and also ignimbrite, together with a variable development of interbedded conglomerates and lithic arenites.

The formation is also exposed on the Karuah-Tea Gardens road west of Bulga Creek (067645 P.S.). The flows which are well developed at Karuah Trig. (036636 P.S.) continue to the southern side of Port Stephens, where an extensive development of lavas is indicated by small inliers cropping out through sand dunes and alluvial deposits. Whilst all these outcrops have been shown on the map as belonging to the Nerong Volcanics, it is not improbable that some of the more westerly beds should be placed in the overlying Crawford Formation. Separation must await the formal description of the sequence in the Stroud-Gloucester Syncline. Sussmilch and Clarke (1928) have given a detailed petrological account of the Port Stephens lavas.

(ii) *Eastern limb of the Girvan Anticline/Western limb of the Myall Syncline*—The formation outcrops on the Tea Gardens-Bulahdelah road, where it overlies the Wootton Beds and is overlain by the Crawford Formation, there being no development of the Conger Formation in this locality. Members present include andesitic pitchstones, andesites, toscanites, an ignimbrite and minor amounts of lithic arenite. The total section is approximately 1500 ft. thick.

The type section, on the Nerong Forestry road, shows a sequence which is similar to that on Bulahdelah Mountain about 1 mile to the

north. In this area the Conger Formation is present beneath the volcanics. The type section is as follows:

	Feet
Ignimbrite	100
Toscanite	550
Lithic arenite (medium grained) ..	200
Toscanite	300
Andesite (Martins Creek type) ..	200
Conglomerate	100
Toscanite (at base)	950
	<hr/>
	2,400

All the toscanite flows have a reddish colouration due to weathering. The uppermost 100 ft. of the section consists of a 'toscanite' in which there is a progressive reduction in the amount of phenocrysts so that finally the rock is felsitic in texture. Thin sections of this rock consist of kaolinized feldspar, resorbed quartz and oriented biotite fragments set in a quartzo-feldspathic groundmass which has devitrified into welded shards, indicating it to be an ignimbrite. Similar textural variation in the other toscanites in the sequence may exist.

On the western side of the upper Crawford River is a ridge extending north from Purgatory Mountain through Winn's Hill. It consists of a narrow band of Nerong Volcanics dipping to the west, in direct contrast to the same beds at Bulahdelah Mountain which dip to the east. Only toscanite lava of 500–600 ft. thickness is exposed at Purgatory Mountain and Winn's Hill (Jarrah Road). On the Crawford River-Stroud road about 2 miles west of the river, mudstones of the Wootton Beds are overlain by a thin bed of toscanite, coarse conglomerates, arenites, a crystal tuff, a dacite flow and then further sediments of the overlying Crawford Formation.

(iii) *Eastern limb of the Myall Syncline*—A thin development of the Nerong Volcanics crops out on the western edge of the Myall Lake and northwards. At Johnson's Hill (374835 B.) reddish stained toscanites and a dacite flow outcrop beneath the fossiliferous Crawford Formation. Near Violet Hill, the volcanics are represented by dacite flows which extend in a narrow band not greater than 100 ft. thick from Bull's Bay (376865 B.) north to Hewitt's Lookout. Due to an east-trending fault, this lava (50 ft. thick) has been moved westward towards the axis of the Myall Syncline where it is found in the Boolambayte Section of Voisey (1940). At both Hewitt's Lookout and in the Boolambayte Section lithological correlation is supported by overlying fossiliferous

beds. The same dacite flow is again found in its undisturbed position on the western slope of O'Sullivan's Gap (O'Sullivan's Gap Section—Voisey, 1940) and northwards on the Wang Wauk Forest Way. Beyond this, the outcrop is obscured by vegetation.

Crawford Formation

DEFINITION

Synonymy—Upper Kuttung Series (Main Clastic Zone) (Osborne, 1950).

Derivation—Crawford River, a major tributary to the Myall River, situated to the west of Bulahdelah.

Type Section—Booral-Bulahdelah road from the eastern foot of Bulahdelah Mountain (160871 B.) to east of the former site of the Crawford River School (198880 B.).

Lithology—Lithic arenites and friable and indurated mudstones with small amounts of conglomerate, crystal tuff and cherty beds, marine throughout.

Thickness—Approximately 8000 ft. in the type section with the possibility that the thickness may be slightly greater on the eastern side of the Myall Syncline.

Age and Relations—Middle and Upper Carboniferous. The formation is conformable with the underlying Nerong Volcanics and the overlying Alum Mountain Volcanics.

DESCRIPTION

(i) *Western limb of the Myall Syncline*—South of the Booral-Bulahdelah road, poor exposures of lithic arenites and mudstones occur along the Tea Gardens road and as a number of isolated outcrops on the shores of Broadwater Lake. Some beds carry *Rhacopteris* fragments.

The type section commences at the eastern foot of Bulahdelah Mountain where lithic arenites occur interbedded with fine conglomerates. About 50 ft. above the base of the formation there is a thin weathered arenite bed containing *Marginirugus barringtonensis alatus* Campbell (M27-163870 B.). This is overlain by further lithic arenites which crop out as far as the Nerong Forestry road turnoff (167872 B.). After a short gap in the section, friable mudstones and lithic arenites are followed by black indurated mudstones together with several bands of crystal tuff and chert which are well exposed in a quarry (169883 B.). Along the southern side of the river there is 1000 ft. of alternating fine lithic arenites and friable mud-

stones. Arenites predominate in this exposure, individual beds having an average thickness of 1 ft. and a maximum thickness of 5 ft. The mudstones contain fragments of *Rhacopteris*. The remainder of the section is composed of similar sediments with some arenites showing well developed plain cross bedded laminations. In a series of gravel pits, east of the former site of the Crawford River school (198880 B.), fine conglomerates containing uniformly rounded lava pebbles are exposed. They are followed by the youngest member of the formation, a conglomerate which differs from the others in the sequence in that the pebbles vary in composition and size distribution. This rock forms very bold outcrops and is a valuable marker horizon. The overlying rocks belong to the Alum Mountain Volcanics.

(ii) *The Crawford Anticline*—The exposures in this structure consist mostly of beds belonging to the Crawford Formation. In general, these beds have low dips and are composed of arenites, mudstones (with *Rhacopteris* fragments) and a few conglomerates. On the axis, near the top of the range (158047 B.) a leucocratic dolerite with patches of a secondary zeolite, probably phillipsite, is exposed. The age and stratigraphic relationships are unknown but it appears as if the dolerite may be a member of the formation.

Exposures along the Crawford River indicate a major disturbance in the area. Most of the beds are fractured, steeply dipping and even slightly overturned.

No marine fossils were collected from the large area covered by the anticline.

(iii) *The Crawford River Fault Block*—Above the Nerong Volcanics on the Crawford River-Stroud road, there is a sedimentary sequence of lithic arenites and mudstones dipping to the west. Some of the arenites show plain cross bedded laminations. About 500 ft. above the Volcanics, the index fossil *M. barringtonensis alatus* and *Lissochonetes* sp. were found (M32-088063 B.). Approximately 70 ft. above this again, further marine fossils were located (M33-086065 B.). They include *Tornquistia* sp. *Alispirifer* sp. and a rhynchonellid (with identical internal structures and external form to *Rhynchopora* sp. but without a punctate shell) herein referred to as ? *Rhynchopora* sp. Similar sediments outcrop westwards to Black Bullock Creek where further marine fossils were collected (M34-080063 B.) namely *Neospirifer* cf. *pristinis* Maxwell, *Australosutura gardneri* Mitchell and several unidentified gastropods. The above

fauna places this bed in the *Levipustula* zone (see section on Palaeontology, below).

Faulting along Black Bullock Creek has brought west dipping Wootton Beds of the Girvan Anticline in contact with this exposure of the Crawford Formation.

(iv) *Myall Lake District*—In the Myall Lake region at Johnson's Hill, Nerong Volcanics (toscanite and dacite) are overlain by fine lithic arenites and indurated mudstones. Marine fossils occur in abundance in this area. A chonetid-rhynchonellid fauna including *Tornquistia* sp., *Alispirifer* sp., and ? *Rhynchopora* sp. was collected at (M16-371831 B.) and on the eastern slope of the same hill *M. barringtonensis alatus* and *Tornquistia* sp. occur at (M2-368832 B.) in a bed approximately 600 ft. above the base of the formation. On Goat Island, indurated mudstones and arenites contain *Thamnopora* sp. and *Alispirifer* sp. (M3-362837 B.). On Sheep Island similar sediments with an interbedded crystal tuff and an ignimbrite are overlaid by beds containing an abundance of *Levipustula* sp., *Fistulina* sp., a fenestellid and some crinoid stems (M14-355837 B.). Outcropping on the peninsula between the two segments of Boolambayte Lake are mudstones and arenites which on the shore of the lake near Bombah Point (M1-342805 B.) contain a marine fauna which has been recently described by Campbell (1959, 1961). This bed may well be the faulted equivalent of that occurring on Sheep Island.

Rocks similar to those on Johnson's Hill, containing marine fossils, occur to the north at the following localities:

(M15-374855 B.)—*M. barringtonensis alatus* and *Tornquistia* sp.

(M17-372851 B.)—*M. barringtonensis alatus* and a large punctate spiriferid (a new species of ? *Punctospirifer* sp., width up to 6 cm.).

(M18-373867 B.)—*M. barringtonensis alatus*, *Alispirifer* sp. and the large punctate spiriferid.

(M19-369870 B.)—small unidentified pelecypod (as occurs between *M. barringtonensis* and *Levipustula* sp. in the Barrington Section—Voisey, 1940).

(M20-369870 B.)—*Thamnopora* sp., *Fistulina* sp. and an unidentified athyrid.

Stratigraphically M20 is about 70 ft. higher than M19, which in turn is about 2000 ft. above M18.

(v) *Section from Hewitt's Lookout to Bulahdelah*—Stratigraphically above the dacite flows at Hewitt's Lookout, lithic arenites and indurated mudstones occur interbedded with considerable thicknesses of conglomerate and conglomeratic sediments. Fossil horizons similar to those mentioned previously are developed in this section:

(M22-342930 B.)—*Tornquistia* sp., *Alispirifer* sp. and ? *Rhynchopora* sp.

(M23-339925 B.)—*Alispirifer* sp., *Spinuliplica spinulosa* Campbell, *Composita magnicarina* Campbell, *Levipustula* sp., *Booralia ovata* Campbell, *Peruvipsira kuttungensis* Campbell, and *Streblochondria histion* Campbell. This fauna from the *Levipustula* zone contains elements of the Boolal Formation (Campbell, 1961) and of the Kullatine Series on the north coast.

Rocks following the *Levipustula* bed include a crystal tuff and then further arenites and mudstones in outcrops extending as far as the township of Boolambayte. The road section from Boolambayte to the Pacific Highway consists mainly of green grey mudstones with arenite beds near the top of the sequence. Faulting is evident in a quarry (284940 B.) where arenite beds are contorted. The dip of the beds from Boolambayte to the Highway is almost vertical.

(vi) *Exposures from the Boolambayte Section (Voisey, 1940) to Bulahdelah*—This sequence commences above the dacite horizon of Voisey's (1940) Boolambayte Section. Rock types include friable and indurated mudstones, lithic arenites (some of which have an apple green colouration), crystal tuffs and ignimbrites. Again a number of important fossil localities occur in this region:

(M21-285968 B.)—*M. barringtonensis barringtonensis* and *Tornquistia* sp.

(M12-279981 B.)—*M. barringtonensis alatus*, *Alispirifer* sp., ? *Rhynchopora* sp. and *Lissochonetes* sp.

(M28-284966 B.)—*M. barringtonensis alatus*, *Alispirifer* sp. and ? *Rhynchopora* sp.

(M11-277960 B.)—Unidentified pelecypods.

(M24-276986 B.)—*Levipustula* sp. and *Composita magnicarina* Campbell.

Most of the beds are vertical with some minor synclinal and anticlinal features.

(vii) *O'Sullivan's Gap Section (Voisey, 1940)*—Voisey has described the section above the Nerong Volcanics on the western slope of the

O'Sullivan's Gap range. The lithology of conglomerates, arenites and mudstones is similar to that on the Forestry roads (Wang Wauk Forest Way) to the north of the Highway.

Alum Mountain Volcanics

DEFINITION

Synonymy—Upper Kuttung Volcanic Stage (Voisey, 1940 ; Osborne, 1950).

Derivation—Alum Mountain (259916 B.) situated immediately east of the village of Bulahdelah.

Type Section—Southern end of Alum Mountain (273903 B. to 262899 B.).

Lithology—Rhyolite, andesitic pitchstone, trachy-andesite, andesite, basalt and inter-bedded sediments.

Thickness—Maximum observed thickness 1600 ft. in the type section.

Age and Relations—Upper Carboniferous (?). Contact with the lower Crawford Formation and the overlying Permian sediments is apparently conformable.

DESCRIPTION

(i) *Western limb of the Myall Syncline*—Succeeding the Crawford Formation at the Gap (231845 B.) on the Tea Gardens-Bulahdelah road is a small thickness of volcanics composed of a bluish amygdaloidal basalt, a trachy-andesite and a purple tinted rhyolite, together with some arenite beds. Permian beds are encountered immediately above the rhyolite.

To the south at the mouth of the Myall River, basalt is overlaid by rhyolites which include both massive and banded varieties.

South of Black Camp Creek, flows of weathered andesite and basalt occur. To the north of the Creek, the flows thin markedly and are replaced by a group of *Rhacopteris* bearing arenites. An andesite flow near Markwell, however, maintains its development. At Upper Myall the sequence consists of arenites and conglomerates together with a greenish trachytic rock exposed west of the Upper Myall School (217087 B.).

(ii) *Eastern limb of the Myall Syncline*—The most conspicuous feature of the Alum Mountain range is the physiographic expression of the vertically dipping rhyolite member. It is a grey-white rock, sometimes massive, sometimes showing excellent flow structure. It outcrops from north of Bulahdelah for some 8 miles to the south near Bombah Point (342804 P.S.). The thickness varies considerably. A few bands

of pitchstone are closely associated with the rhyolite and are best developed at the southern end of Alum Mountain. Near Bulahdelah, the rhyolite contains minor deposits of alunite along its joint planes and these have been exploited commercially. Beneath the rhyolite are irregularly developed andesitic and basaltic flows. On the highway to the north of Bulahdelah where the road crosses the rhyolite, it is underlain by an arenite and then a basalt flow ; whilst south of Alum Mountain, andesites and trachy-andesites are developed beneath the rhyolite.

South of Alum Mountain there is an occurrence of Permian coal measures situated between the basalt-andesite flows and the overlying rhyolite flow. Various theories have been advanced to explain this development. Pittman (1901) first recorded the occurrence in Portion 119 and in the northwest corner of Portion 67, Parish of Bulahdelah. Carey (1934) described the outcrop as a conformable development, but Osborne (1950) considered that these measures were trough faulted into the Carboniferous sequence. The beds themselves consist of a thin development of conglomerate, soft white arenite and about 20 ft. of banded coal. None of these rocks shows extensive signs of disturbance. If it is accepted that the sequence is conformable then there must be some doubt that the Alum Mountain Volcanics are Carboniferous in age. At present the evidence is insufficient to warrant departure from the age accepted for the volcanics.

North of Bulahdelah, beyond the two east trending faults, the lavas thin out and disappear. A rhyolite flow (20 ft.) outcrops north of Voisey's Boolambayte section for a further distance of approximately 3 miles beyond which its extension is concealed. The flow is associated with a vitric tuff, the rest of the sequence being a considerable thickness of lithic arenites and minor conglomerates.

Markwell Coal Measures

DEFINITION

Synonymy—Lower Coal Measures (Osborne, 1950, p. 29).

Derivation—Markwell village (216015 B.).

Type Section—Exposures at the Gap (231845 B.) on the Tea Gardens-Bulahdelah road.

Lithology—Conglomerates, pebbly arenites, shales and impure coal seams.

Thickness—As exposed this formation does not exceed 40 ft.

Age and Relations—Permian. In most of the exposures, the measures conformably follow the rhyolite or arenites of the Alum Mountain Volcanics (see exception mentioned above).

DESCRIPTION

The oldest Permian strata within the Myall Syncline consist of a sequence of lenticular conglomerates, pebbly arenites, shales and a few impure coal seams. Mapping of the formation was based largely upon a basal conglomerate member.

On the western limb of the syncline, south of the Booral-Bulahdelah road, the only outcrop is found at the Gap on the Bulahdelah-Tea Gardens road. In this locality, Carboniferous rhyolites are succeeded by a steeply dipping group of conglomerates, arenites, plant-bearing shales and several decomposed bands of coal. The pebbles and boulders of the conglomerates are usually not greater than 3 in. in diameter. Laterally and vertically the conglomerates are replaced by more sandy beds which show current bedding or by impure coal seams. Above these sediments shales containing an abundance of *Glossopteris* occur.

On the northern side of Booral road the outcrops are poor as far as the old road junction (217975 B.) just north of Rosenthal where there is a quarry in the basal conglomerate. This member extends northwards through Markwell almost as far as Upper Myall. No further coal was observed on this western side of the syncline.

On the eastern limb of the syncline the measures commence a little south of Upper Myall where the outcrop is found on the banks of the Myall River (218062 B.). Here coal is associated with other sediments. The outcrop continues south to cross the 'back road' along the Myall River at the cross road (233033 B.) leading to Markwell. At this locality 20 ft. of conglomerate is exposed in a quarry and a little further south carbonaceous shales with some soft mudstones crop out on the roadside. No further measures crop out as far south as Bulahdelah.

As mentioned previously, *Glossopteris*-bearing sediments (including coal) occur in Portions 67 and 119, Parish of Bulahdelah beneath Carboniferous rhyolites. Carey (1934) recorded outcrops of at least two coal seams in Portion 67 together with conglomerate, arenite and fossiliferous shales which dip S 45° W at 60°. Outcrop in Portion 119 is presumably a continuation of the same horizon, there being approximately 20–25 ft. of coal seams and

arenites present. Some doubt exists as to the structural position of this bed. If it is conformable, then it is overlain by rhyolites and arenites, the latter bearing *Rhacopteris* fragments. The other unsatisfactory alternative is to postulate, without much evidence, the presence of trough faulting. Neither solution can be accepted as satisfactory at present, although it is possible palaeontologically for this to be a normal sequence as has been recorded in the Itarare Group of South America (Caster, 1952), where *Rhacopteris* flora is found stratigraphically above *Glossopteris* flora.

Bulahdelah Formation

DEFINITION

Synonymy—Upper Marine Series (Osborne, 1950, p. 29).

Derivation—Bulahdelah Village (245925 B.).

Type Section—This formation is very poorly exposed so that the type section is composite, being made up of the creek and road sections from the foot of Alum Mountain (at the southern end) down to the Myall River. This includes the exposures along the Bulahdelah-Bombah Point road just out of Bulahdelah.

Lithology—Arenites (grey-green and brown, some with pebble bands) and shales.

Thickness—Maximum approximate thickness is a little less than 3000 ft.

Age and Relations—Permian. Conformable with Markwell Coal Measures. No overlying formations are developed in this region.

DESCRIPTION

The outcrop of this formation is generally poor. Stratigraphically above the Markwell Coal Measures, where they are developed, is a sequence of weathered arenites largely concealed in the axial region of the Myall Syncline by alluvial deposits of the Myall River.

The sandstones in the type section on the eastern side of Bulahdelah have yielded a marine fauna. These fossiliferous beds occur about 100–150 yards past the Old Court House on the Bombah Point Road (M4-246911 B.). Fossils were first collected from this locality by Pittman (1901). The faunal list (by Dun) is quoted without alteration from the original—" *Platyschisma oculum*, *Aviculopecten tenuicollis*, *Aviculopecten leniusculus*, *Merismopteria macroptera*, *Chaenomya* (?) *etheridgei*, *Aphanaia* and *Spirifera duodecimcostata* ".

In the type section the lowest observed strata include grey-green, fine grained arenites which carry distinct pebble bands. These beds are

quite resistant and can be traced for some distance south. Overlying these rocks are silty and sandy shales succeeded by considerable thicknesses of iron stained, crumbling arenites which are in places quite calcareous and in which the above fossils occur.

On the northern side of the east-trending faults, near Bulahdelah, a conspicuous ridge composed of arenites extends for nearly 3 miles parallel to the 'back road' to Upper Myall.

On the western side of the Myall Syncline the area of development is more extensive. Unfortunately the rocks are largely concealed by shallow alluvium. Road cuttings on the Booral road at locality (208883 B.) display badly weathered arenites. Further exposures occur on the Upper Myall road near the Myall River (226955 B.) and in the vicinity of Markwell, where the branch road crosses the River (219022 B.).

As stated elsewhere, correlation of these Permian beds with the standard section in the Hunter Valley is unreliable.

Tertiary to Recent Deposits

Recent Alluvial Deposits—As can be seen on the geological map, a large portion of the region is covered by alluvial and aeolian deposits. Where relatively high ground occurs in the coastal belt, it undoubtedly consists of bed rock that is obscured by a shallow sand cover. A series of sand dunes are developed parallel with the coastline and their pattern is excellently pictured on the aerial photographs. This region has been the subject of geomorphological study by Thom (1960).

Alluvial deposits are developed along the Myall and Boolambayte Rivers.

Tertiary (?) Dykes—Along the coastline, particularly south of Port Stephens, there occurs a swarm of basalt dykes intrusive into the exposed lava sequence (Nashar and Catlin, 1959). The dykes are fairly regular bodies varying from a few inches up to several feet in width. They are intruded along joints of the flows. Partly assimilated blocks of Carboniferous lavas are of quite frequent occurrence.

At various places inland, several dykes have been observed. Generally these are found in excavations where their state of decomposition is quite advanced.

These dykes are intrusive into Permian strata in the Newcastle area and into Mesozoic beds further south. On this evidence, it seems most likely that they were associated with the widespread basalt extrusions of the Tertiary Period.

Structural Geology

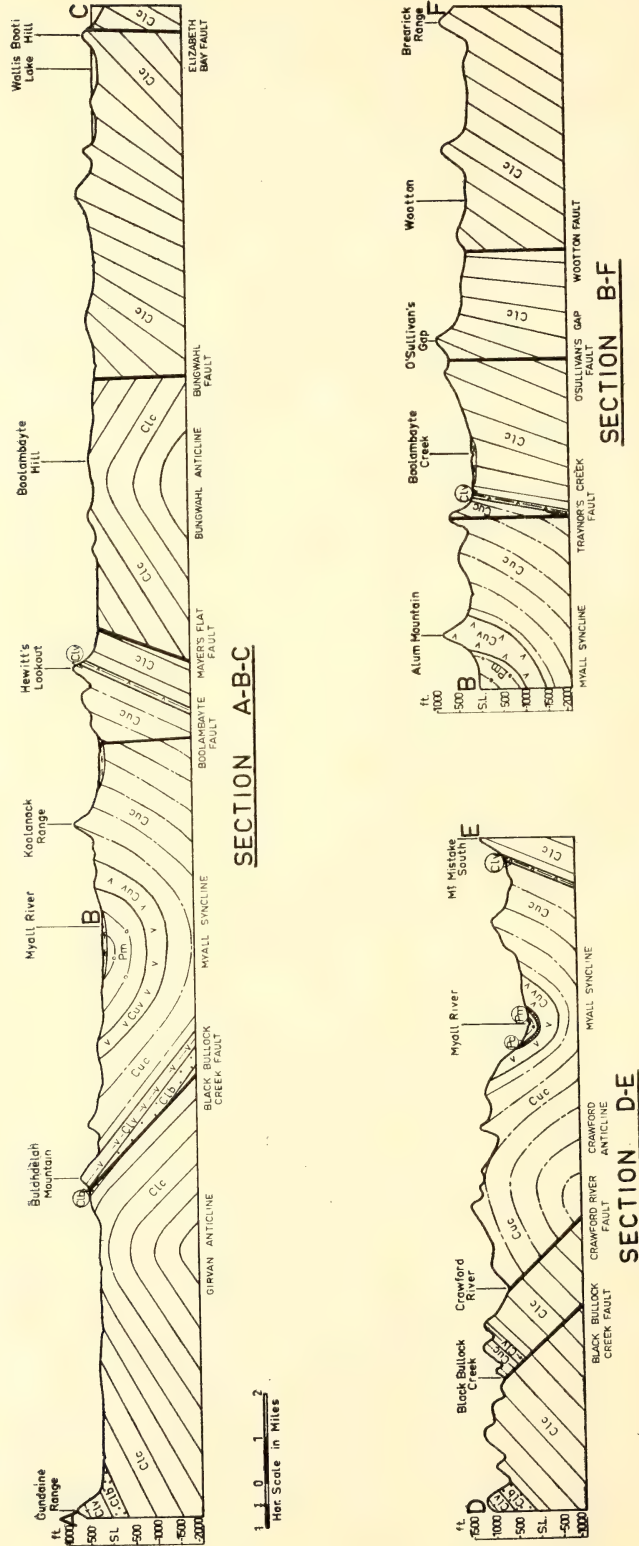
The main structural features consist of a number of subparallel synclines and anticlines trending from due north to N 40° W, most of which have been subsequently disrupted by faulting of normal, transcurrent and thrust types.

FOLDING

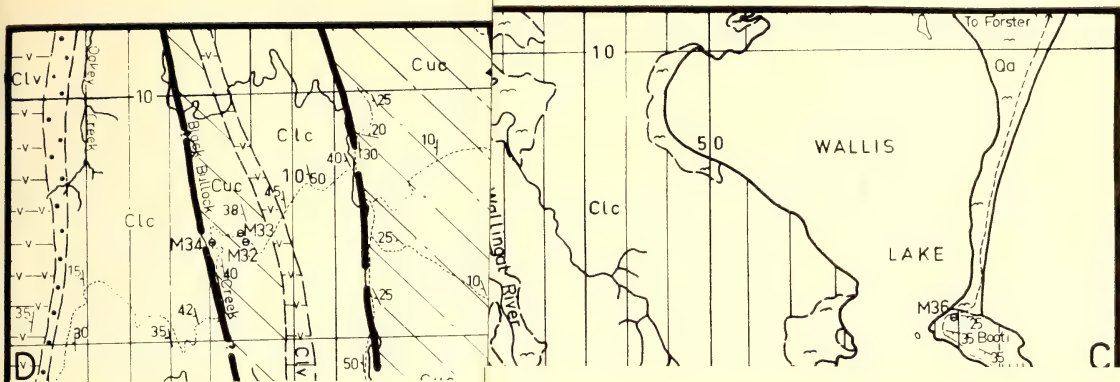
(i) *The Girvan Anticline*—The rocks on the western edge of the map dip to the west into the adjoining Stroud-Gloucester Syncline, a structure in which the sequence is closely comparable with that of the area under investigation. The Girvan Anticline, which exposes Wootton Beds in its crestral area, is an asymmetrical fold with the beds dipping more steeply on the eastern flank. Nerong Volcanics on the western flank extend south to Port Stephens in a broad arc which suggests probable closure of the fold in that region.

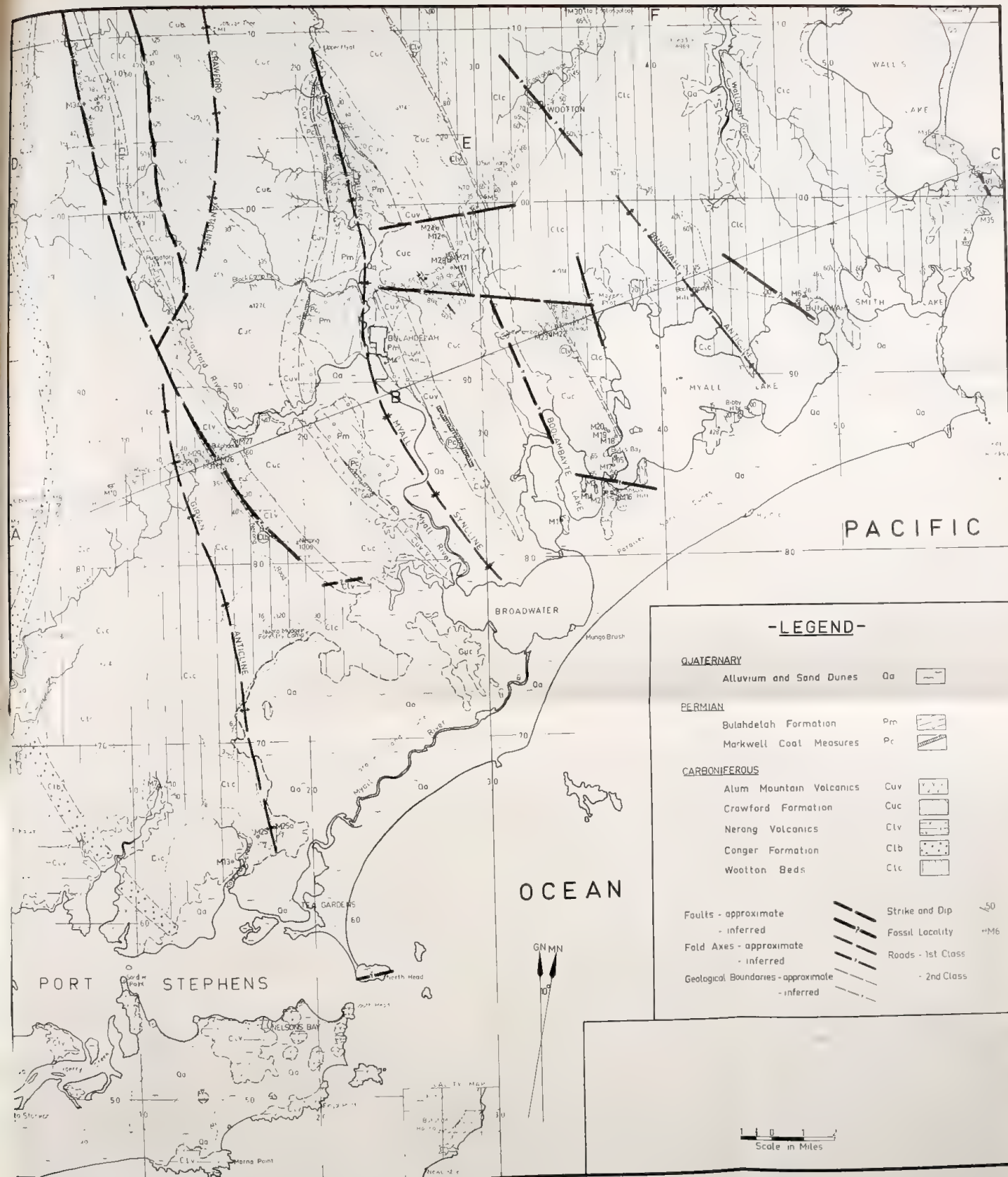
On the northern side of the Bulahdelah-Booral road, the anticline loses its simple nature. Faulting has concealed the axis and the eastern limb beneath the Crawford River Fault block. The beds of the western limb exposed in this area dip more steeply than do their southern equivalents. The above faulting, which follows Black Bullock Creek, is assumed to extend down the eastern side of the anticline. Its effects are exposed in the Conger Formation on Bulahdelah Mountain and in view of the probable magnitude of the fault in the north, it seems that a considerable portion of the sequence may have been lost in the vicinity of Bulahdelah Mountain.

(ii) *The Crawford Anticline*—In the region from Purgatory, north to Cabbage Tree Mountain this anticlinal structure is developed. The Crawford Formation is exposed in the crestral area from the Crawford River to the adjoining Myall Syncline. The western limb of this fold is truncated by a fault developed along the Crawford River causing the Crawford Formation to come in contact with Wootton Beds. The southern termination of the anticline is complex. The beds on the eastern limb continue south where they join with the Nerong Volcanics of Bulahdelah Mountain to form the connecting limb between the Girvan Anticline and the Myall Syncline, whilst the beds of the western limb are lost in the thrust fault along the Crawford River. The position of the axis is clear between the head of Black Camp Creek and Purgatory but thereafter its southern termination is conjectural. The position of the



TEXT-FIGURE 2
Sections to accompany geological map of the Bulandelah-Port Stephens District, N.S.W.





Geological Map of the Bulahdelah-Port Stephens District

axis shown on the map is the best interpretation on present evidence.

(iii) *The Myall Syncline*—The structure of this fold is well defined by the lithological marker horizons which occur on both sides of the Myall River Valley. The fold appears to close to the north near Upper Myall, this being illustrated by basal Permian conglomerates which swing markedly in their strike, for example, at Markwell the strike is N 15° W whilst at Newell's Creek it is N 20° E. Due to the steep dips which persist in the area, it is essential to postulate the occurrence of normal faulting.

From south to north the axial trend changes from N 25° W to N 5° W and back again to N 25° W, the deflection being presumably related to the faulting of the steeper eastern limb. The marker beds on the western side of the syncline bend in a broad arc from Black Camp Creek to the Gap on the Tea Gardens-Bulahdelah road. This feature is not reflected in the eastern limb of the fold which has suffered considerable deformation by faulting. Most of the east flanking Carboniferous beds are in a vertical or near vertical position.

(iv) *The Bungwahl Anticline*—An anticlinal axis east of the Myall Syncline occurs in the Boolambayte Hill area on the northern shore of Myall Lake. Evidence for this fold may be observed in the road section from Hewitt's Lookout to Bungwahl. Here, beds dipping steeply west (65° W) at the eastern foot of Hewitt's Lookout are abruptly replaced by shallow dipping beds (20° W) which gradually flatten in the axial region and turn over to dip to the east as far as Bungwahl where a fault has brought them in contact with beds dipping regionally to the west. The position of the axis can be inferred on the southern side of Myall Lake but it does not extend as far north as the Pacific Highway at Wootton. This implies that it has plunged or faulted out in the intervening country or that the fault at Wootton has been responsible for its disappearance.

Apart from this small fold, the rocks east of Wootton and Bungwahl dip within the range of 30° to 60° W. This results in the exposure of a large section of Wootton Beds across to the coastline.

FAULTING

(i) *The Crawford River Fault Block*—In the Upper Crawford River area, thrust faulting has seriously disrupted the stratigraphic sequence. This is illustrated by the geological cross section D-E where the Nerong Volcanics appear twice

in the one section with both exposures dipping to the west. This anomalous structural attitude has been interpreted by placing a thrust fault along both the Crawford River and Black Bullock Creek thus enclosing a wedge of strata which has been called the Crawford River Fault Block.

The thrust fault along the Crawford River is inferred from the presence of contorted and pulverized sediments along the river and by the juxtaposition of the Crawford Formation, exposed in the Crawford Anticline, with Wootton Beds which occur to the west and whose stratigraphic position was established by overlying fossiliferous sediments.

The sequence in the fault block from east to west consists of Wootton Beds, Nerong Volcanics and the Crawford Formation, all of which dip to the west. As this sequence is repeated on the western side of Black Bullock Creek forming the eastern limb of the Stroud-Gloucester Syncline it was inferred that thrusting was again responsible for the structural attitude. The linear nature of Black Bullock Creek has led to the placing of the western thrust in that position. This fault is inferred to extend south to the Booral-Bulahdelah road at the western foot of Bulahdelah Mountain where the deformation of the Conger Formation conglomerates provide definite evidence of faulting.

(ii) *Faulting associated with the Myall Syncline*—At the northern extremity of the syncline, a fault has been postulated to explain closure of this fold. Two east trending faults on the eastern limb have brought a wedge of Carboniferous strata towards the axis of the syncline, and there is an unconfirmed possibility that the Alum Mountain ridge has been pushed westwards into its present position.

The wedge, bound by the east-trending faults north of Bulahdelah, contains strata in a vertical or overturned position. Some subsidiary folding is present.

No evidence has been found to support the contention of Osborne (1950) that Alum Mountain is an horst block bound on both sides by vertical faults.

A further anomalous occurrence is that of the Permian coal measures, within the Alum Mountain Volcanics, south of Bulahdelah. On present evidence these beds are presumed to have been strike faulted into their present position.

(iii) *Faulting east of the Myall Syncline*—A strike fault is tentatively placed along Boolambayte Creek to explain the excessive

thickness of the Crawford Formation in that area. This position for the fault is supported by the duplication of the *Levipustula* horizon at M14 (355837 B.) and M1 (442805 B.).

Three strike faults have been observed in the Bungwahl-Wootton area. The first of these at Bungwahl brings east dipping beds of the Bungwahl Anticline in contact with west dipping Wootton Beds. The possibility of a synclinal structure in lieu of this fault is considered to be unlikely.

The fault in the vicinity of Wootton brings vertical to overturned beds in contact with similar strata which dip at 15° W but which quickly return to the regional dip of 50° W. This fault appears to mark the site of what should have been the northern extension of the Bungwahl Anticline.

The third fault is developed at the eastern foot of Hewitt's Lookout on the Bungwahl-Bulahdelah road where shallow dipping beds (20° W) of the Bungwahl Anticline are overlain abruptly by steeply dipping beds (65° W) of the Lookout Range. It would appear probable that strike faulting is responsible for the change in dip. It is possible that this faulting may be connected with the dislocation of bedding at Wootton.

At Johnson's Hill on Myall Lake, a sharp swing of strike in the bedding has prompted the placing of a fault between Violet Hill and Johnson's Hill. This dislocation was previously noted by Carey (1934).

Dislocation of bedding indicates the presence of further small faults along the coastline and in some of the offshore islands.

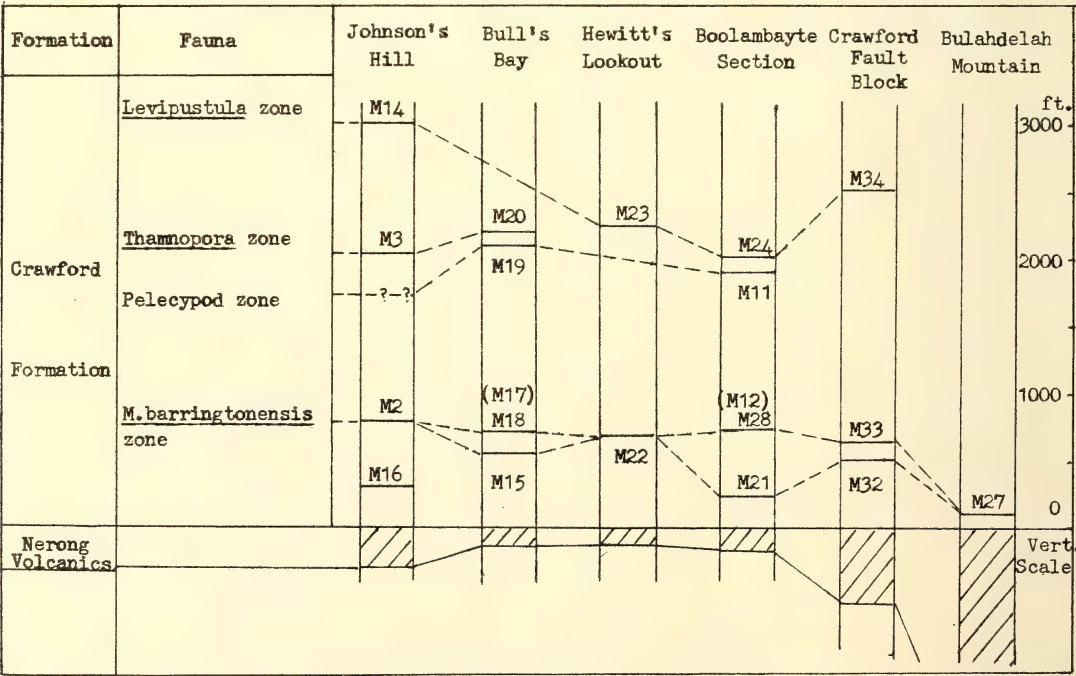
Palaeontology

In this district, fossils occur abundantly throughout the Crawford Formation and in the upper portion of the Wootton Beds. Thirty-six localities (M1-M36) were investigated and of these only ten had been previously recorded.

The five faunal zones listed below have formed the basis for most of the mapping and correlation.

WOOTTON BEDS

Fossils are found mainly in the upper beds and at present the lower portion cannot be divided on the basis of the few contained fossils. Important forms present in the upper beds include *Schizophoria* sp., *Rhipidomella australis* (McCoy), *Leptagonia* sp., *Dictyoclostus* cf. *simplex* Campbell, *D. cf. paradoxus* Campbell, *Cleiothyridina* sp., *Brachythyris davidii* (Dun), *B. pseudovalis* Campbell, *Pustula abbotti* Campbell,



TEXT-FIGURE 3
A correlation chart for fossil localities in the Crawford Formation

Daviesiella cf. *aspinosa* (Dun), *Werrieca* cf. *australis* Campbell, *Phricodothyris uniplicata* Campbell, *Spirifer lirellus* Cvancara, and *Goniocladia* sp.

Collectively the faunas present at M8, M13, M25, M29 and M31 are very similar to those found at Babbinsboon (Campbell, 1957), in 'Zone U' of the Barrington Section (Voisey, 1940), and in the horizon on the western limb of the Stroud-Gloucester Trough recently described by Cvancara (1958).

It is evident that there is a close palaeontological correlation between these regions which indicates that the Wootton Beds have at least a partial time-rock equivalence with sections that have been previously assigned to the Lower Burindi Series.

CRAWFORD FORMATION

This formation contains four important zones which can be correlated with established Carboniferous sections.

(i) *Marginirugus barringtonensis* zone—This lowest zone in the Crawford Formation contains the following species: *Marginirugus barringtonensis barringtonensis* Campbell, *M. b. alatus* Campbell, *Tornquistia* sp., *Lissochonetes* sp., *Rhynchopora* sp., *Alispirifer* sp. and ? *Punctospirifer* sp.

This fauna has been found at seven localities on the eastern side, and two on the western side, of the Myall Syncline. Within the Boolambayte Section (Voisey, 1940), *M. barringtonensis* and its subspecies has been found to occur over a stratigraphic range of some 600 ft. from the base of the Crawford Formation, this being equal to the greatest observed range in both N.S.W. and Queensland.

The chonetid which is commonly associated with *Marginirugus* is provisionally assigned to the genus *Tornquistia* Paeckelmann on the grounds of their close internal similarity despite the fact that *Tornquistia* as originally defined is much smaller than the present specimens.

As well as the alate *Alispirifer* sp., there is a large punctate spiriferid of width up to 6 cm. This is much larger than any other known *Punctospirifer* and will probably form a new species.

(ii) Pelecypod zone—At several distinct localities, there occur at least two unidentified pelecypods very similar to those contained in the Barrington Section of Voisey (1940). There is no associated fauna.

(iii) *Thamnopora* zone—This zone is characterized by the coral *Thamnopora* sp. together with *Alispirifer* sp. and *Fistulammina* sp.

The excellent moulds of *Thamnopora* sp. belong to a large species which has a branch diameter of from 10 to 18 mm. and a corallite diameter of from 2 to 4 mm.

(iv) *Levipustula* zone—This zone has been the subject of a detailed examination by Campbell (1959, 1961) in the Myall Lake area (M1-342805 B.) and near Booral (M9-018840 Dungog).

From the various localities in the present area the following important forms have been collected: *Alispirifer* sp., *Neospirifer* cf. *pristinis*, *Spinuliplica spinulosa*, *Composita magnicarina*, *Levipustula* sp., *Booralia ovata*, *Peruviospira kuttungensis*, *Streblochondria histion* and *Australosutura gardneri*.

It is evident from the study of these faunas that they contain elements of both the Booral fauna (M9) and another fauna recently collected and described by Campbell (personal communication) from the Kullatine Series (Voisey, 1938, 1939) near Taree.

No further faunas have been located above the *Levipustula* zone in the present area.

Acknowledgement

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Appendix

A LIST OF PALAEOLOGICAL LOCALITIES

- M1 —(342805 B.) Shore of Boolambayte Lake, opposite and just north of Bombah Point. (Campbell, 1961.)
- M 2—(368832 B.) Western side of Johnson's Hill, Myall Lake. (Osborne, 1950.)
- M 3—(362837 B.) Goat Island, Boolambayte Lake. (Carey, 1934.)
- M 4—(246911 B.) Bombah Point Road, 150 yards past the old Court House in Bulahdelah. (Pittman, 1901.)
- M 5—(305005 B.) O'Sullivan's Gap. (Voisey, 1940.)
- M 6—(482943 B.) Bungwahl township.
- M 7—(115677 P.S.) Bundabah Creek crossing, Tea Gardens-Karuah road. (Osborne, 1950.)
- M 8—(058836 B.) Rose Hill Quarry, Booral-Bulahdelah road.
- M 9—(018840 Dungog.) Quarry 2 miles east of Booral on Booral-Bulahdelah road. (Osborne, 1950; Campbell, 1961.)
- M10—(090847 B.) Road quarry west of Girvan on Booral-Bulahdelah road.
- M11—(277960 B.) 200 yards up Flooded Gum road, 4 miles north of Bulahdelah.
- M12—(279981 B.) One-half mile on track east of point 2 miles along Koolnock road, 4 miles north of Bulahdelah.
- M13—(156635 P.S.) Western bank of Kore Creek, 2 miles south of Tea Gardens-Karuah road.
- M14—(355837 B.) Sheep Island, Boolambayte Lake.
- M15—(374855 B.) Southern side of Bull's Bay, Myall Lake.
- M16—(371831 B.) Eastern side of Johnson's Hill, Myall Lake.
- M17—(372851 B.) East of Violet Hill, Myall Lake.
- M18—(373867 B.) Northern side of Bull's Bay, Myall Lake.
- M19—(369870 B.) One-half mile west along spur on the northern side of Bull's Bay, Myall Lake.
- M20—(369870 B.) 30 yards west of locality M19.
- M21—(285968 B.) Lower *Marginirugus* horizon in Boolambayte Section. (Voisey, 1940.)
- M22—(342930 B.) Western side of Hewitt's Lookout, Bulahdelah-Bungwahl road.
- M23—(339925 B.) One-half mile west of locality M22 on the same road.
- M24—(276986 B.) Two miles along Koolnock road, 4 miles north of Bulahdelah.
- M25—(168647 P.S.) Quarry 2 miles north of Tea Gardens on the Tea Gardens-Karuah road.
- M25a—(180653 P.S.) Quarry 2 miles north of Tea Gardens on the Tea Gardens-Bulahdelah road.
- M26—(152860 B.) Road cutting in the Conger Formation on Bulahdelah Mountain.
- M27—(163870 B.) Eastern foot of Bulahdelah Mountain on the Booral-Bulahdelah road.

- M28—(284966 B.) Upper *Marginirugus* horizon above M21 in the Boolambayte Section.
- M29—(141860 B.) Road cutting 1 mile west of Bulahdelah Mountain on the Booral-Bulahdelah road.
- M30—(176366 K.) One and a half miles north of Coolongolook on the Pacific Highway.
- M31—(146858 B.) Road cutting at the western foot of Bulahdelah Mountain, Booral-Bulahdelah road.
- M32—(088063 B.) Road cutting on the Forestry Commission road from Crawford River to Stroud.
- M33—(086065 B.) As above.
- M34—(080063 B.) Road cuttings on the eastern bank of Black Bullock Creek on the above forestry road.
- M35—(586988 S.R.) Southern side of the headland at the northern end of Bluey's Beach.
- M36—(557034 S.R.) Quarry at the northern end of Booti Hill, Bungwahl-Forster road.

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On the Theory of Two-Dimensional Slotted Wind Tunnels

A. H. Low

School of Mathematics, University of New South Wales, Kensington, N.S.W.

I. Introduction

In his recent book, Woods (1961) has revived the problem of determining the drag on a symmetrical aerofoil placed midway between the parallel walls of a slotted wind-tunnel. Essentially, the problem is that of finding the flow past a two-dimensional aerofoil of given shape symmetrically placed in a stream of finite width, $2h$; the average boundary condition on the stream is taken to be, for a wall parallel to the undisturbed direction of the stream,

$$\frac{\partial \varphi}{\partial x} + A \frac{\partial^2 \varphi}{\partial x \partial n} = 0 \quad \dots\dots\dots (1)$$

where φ is the perturbation potential of the flow in the tunnel; x is the direction of the undisturbed stream; n is the direction of the outward normal to the wall (and hence to x); and A is a constant related to the slot geometry (see Woods (loc. cit.)).

Previously to Woods, discussions of this problem have been given by Baldwin, Turner and Knechtel (1954) and Maeder and Wood (1956). In each of these treatments, a similar method is employed. This method may be summarized as consisting of three basic steps:

- (i) an approximation to the flow (e.g. a doublet representation of the aerofoil thickness etc.);
- (ii) a transform method (Laplace or Fourier) to solve the perturbation problem involved; and
- (iii) numerical integration to obtain the interference effects at a suitable point on the aerofoil surface. However, the work of Baldwin, Turner and Knechtel is incomplete to the extent that it deals only with the solid blockage component and neglects the wake blockage. Further, the method of Maeder and Wood only allows the calculation of the blockage at a suitable point on the aerofoil, namely the centre of the aerofoil.

The following discussion, which has something in common with each of the methods of the previous investigators, enables the blockage, at any point of the aerofoil surface, to be calculated. The results are found to be in complete agreement with those already established. Also, an alternative method of evaluating an integral which determines the blockage is given in terms of an infinite series of incomplete Gamma functions.

It is found that the blockage, in a slotted tunnel, can be eliminated by suitable choice of the tunnel constant A . It is to be expected that, even if the blockage interference vanishes, corrections may still be necessary to the lift and moment forces acting on the aerofoil. These corrections will be discussed in a subsequent paper.

2. Statement of the Problem

Figure 1 shows a slender aerofoil, whose surface is symmetrical about the chord line, placed at zero incidence on the centre line of a straight-walled slotted wind-tunnel. The presence of these walls will affect the velocity of the flow over the aerofoil surface and it is the magnitude of this velocity increment, the blockage factor, which will be calculated.

If the values appropriate to the flow of an infinite (free) stream past the aerofoil are denoted by an asterisk and the values at $x = \pm \infty$ by the subscripts $\pm \infty$, then the blockage factor at any point (x, y) on the aerofoil surface, $\varepsilon(x, y)$, is defined by

$$\varepsilon(x, y) = \frac{q(x, y)}{q_{-\infty}} - \frac{q^*(x, y)}{q_{-\infty}^*}, \quad \dots\dots\dots (2)$$

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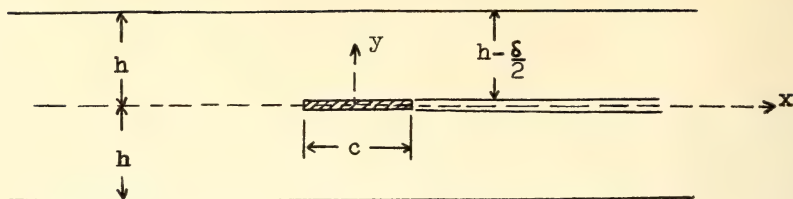


FIG. 1

where (q, θ) is the velocity vector of the flow in polar coordinates. It is convenient, and moreover loses nothing in generality, to let both $q_{-\infty}$ and $q_{-\infty}^*$ equal a suitable reference velocity U so that equation (2) becomes

$$\epsilon = \frac{q - q^*}{U}. \quad \dots\dots\dots (3)$$

3. Mathematical Formulation

It will be assumed that the shape of the aerofoil profile, θ_a , is known and is given by

$$\theta_a(x) = \tan^{-1} \left[\left(\frac{dy}{dx} \right)_a \right], \quad \dots\dots\dots (4)$$

where the subscript a denotes values on the aerofoil surface, and that the wake is a semi-infinite solid sting of thickness δ attached smoothly to the rear of the aerofoil so as to avoid discontinuities in the flow at the trailing edge.

The further assumption of a slender aerofoil permits the use of linear perturbation theory in determining the effects of the tunnel walls on the flow and, as these effects are important at high subsonic speeds to enable the defect of choking to be delayed, it is convenient to use the two-dimensional linearized equation of subsonic compressible (steady) flow (Robinson and Laurmann, 1956, p. 304)

$$\beta^2 \frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial y^2} = 0, \quad \dots\dots\dots (5)$$

where φ is the perturbation velocity potential and

$$\beta^2 = 1 - M^2, \quad \dots\dots\dots (6)$$

M being the Mach number of the flow at infinity upstream (i.e. $x = -\infty$). Also, from (4), we then have

$$\theta_a = \left(\frac{dy}{dx} \right)_a. \quad \dots\dots\dots (7)$$

Moreover, if $2h$ is the tunnel height, symmetry about the tunnel axis, $y=0$, enables us to regard the flow as being through two adjacent channels of height h . The solution of the boundary value problem in either of these two channels will determine the flow in the tunnel.

Considering the upper channel (see Fig. 1), the problem is to determine the function φ satisfying (5) as well as the conditions, on taking the origin of the $z (=x+iy)$ -plane at the aerofoil's mid-chord point,

$$\frac{\partial \varphi}{\partial x} + A \frac{\partial^2 \varphi}{\partial x \partial y} = 0, \quad y=h, \quad \dots\dots\dots (8)$$

$$\left. \begin{aligned} \frac{\partial \varphi}{\partial y} &= U \theta_a & y=0, & |x| \leq \frac{c}{2}, \\ &= 0 & y=0, & |x| \geq \frac{c}{2}. \end{aligned} \right\} \quad \dots\dots\dots (9)$$

4. Determination of the Perturbation Potential

The perturbation potential will be determined by means of the Fourier transform. The Fourier transform of the function $\varphi(x, y)$ will be defined by the equation

when
$$\left. \begin{aligned} \bar{\varphi}(\mu, y) &= \frac{1}{2\pi} \int_{-\infty}^{\infty} \varphi(x, y) e^{i\mu x} dx \\ \varphi(x, y) &= \int_{-\infty}^{\infty} \bar{\varphi}(\mu, y) e^{-i\mu x} d\mu. \end{aligned} \right\} \dots\dots\dots (10)$$

Equations (5) and (10) yield

$$\frac{\partial^2 \bar{\varphi}}{\partial y^2} = \beta^2 \mu^2 \bar{\varphi}$$

from which

$$\bar{\varphi}(\mu, y) = B(\mu) \cosh(\beta y \mu) + C(\mu) \sinh(\beta y \mu). \dots\dots\dots (11)$$

The transforms of equations (8) and (9), using (10), are

$$\bar{\varphi} + A \frac{\partial \bar{\varphi}}{\partial y} = 0, \quad y = h, \dots\dots\dots (12)$$

and

$$\frac{\partial \bar{\varphi}}{\partial y} = \frac{U}{2\pi} \int_{-c/2}^{c/2} \theta_a(x^*) e^{i\mu x^*} dx^*, \quad y = 0, \dots\dots\dots (13)$$

respectively. Substitution of (11) in (12) then gives

$$B = -C \left\{ \frac{\lambda \sinh(\beta h \mu) + \mu \cosh(\beta h \mu)}{\lambda \cosh(\beta h \mu) + \mu \sinh(\beta h \mu)} \right\} \dots\dots\dots (14)$$

where we have written

$$\lambda = \frac{1}{\beta A}. \dots\dots\dots (15)$$

From equations (11) and (13)

$$C = \frac{U}{2\pi\beta\mu} \int_{-c/2}^{c/2} \theta_a(x^*) e^{i\mu x^*} dx^* \dots\dots\dots (16)$$

which, together with equations (11) and (14), gives

$$\begin{aligned} \bar{\varphi}(\mu, y) &= \frac{U}{2\pi\beta\mu} \int_{-c/2}^{c/2} \theta_a(x^*) e^{i\mu x^*} \left\{ \sinh(\beta y \mu) \right. \\ &\quad \left. - \frac{\lambda \sinh(\beta h \mu) + \mu \cosh(\beta h \mu)}{\lambda \cosh(\beta h \mu) + \mu \sinh(\beta h \mu)} \cdot \cosh(\beta y \mu) \right\} dx^*. \dots\dots\dots (17) \end{aligned}$$

On substituting (17) in (10) we find

$$\begin{aligned} \varphi(x, y) &= \frac{-U}{2\pi\beta} \int_{-\infty}^{\infty} \int_{-c/2}^{c/2} \frac{\theta_a(x^*) e^{i\mu(x^* - x)}}{\mu} \\ &\quad \frac{\lambda \sinh(\beta[h - y]\mu) + \mu \cosh(\beta[h - y]\mu)}{\cosh(\beta h \mu) + \mu \sinh(\beta h \mu)} dx^* d\mu. \dots\dots\dots (18) \end{aligned}$$

From (18), or alternatively the form of the integrand in (17), it can be seen that, as $\mu \rightarrow \pm\infty$,

$$\frac{1}{\mu} \frac{\lambda \sinh(\beta[h-y]\mu) + \mu \cosh(\beta[h-y]\mu)}{\lambda \cosh(\beta h\mu) + \mu \sinh(\beta h\mu)} \rightarrow 0 \left(\frac{e^{-\beta y|\mu|}}{|\mu|} \right).$$

Further, near the origin $\mu=0$, provided $\lambda \neq 0$,

$$\frac{1}{\mu} \frac{\lambda \sinh(\beta[h-y]\mu) + \mu \cosh(\beta[h-y]\mu)}{\lambda \cosh(\beta h\mu) + \mu \sinh(\beta h\mu)} \sim \frac{\lambda+1}{\lambda}.$$

Hence, as $\int_{-c/2}^{c/2} \theta_a(x^*) dx^*$ converges absolutely, it is permissible to change, for $\lambda \neq 0$, the order of the integrations in (18). Thus, we write

$$\varphi(x, y) = \frac{-U}{2\pi\beta} \int_{-c/2}^{c/2} \theta_a(x^*) \int_{-\infty}^{\infty} \frac{e^{i\mu(x^*-x)}}{\mu} \cdot \frac{\lambda \sinh(\beta[h-y]\mu) + \mu \cosh(\beta[h-y]\mu)}{\lambda \cosh(\beta h\mu) + \mu \sinh(\beta h\mu)} d\mu dx^* \quad (19)$$

This last equation may be written in the form

$$\begin{aligned} \varphi(x, y) = & \frac{-U}{2\pi\beta} \int_{-c/2}^{c/2} \theta_a(x^*) \int_{-\infty}^{\infty} \frac{e^{i\mu(x^*-x)}}{|\mu|} \left\{ e^{-\beta y|\mu|} \right. \\ & \left. + \frac{e^{-\beta h|\mu|} (|\mu| - \lambda) \cosh(\beta y\mu)}{\mu \sinh(\beta h\mu) + \lambda \cosh(\beta h\mu)} \right\} d\mu dx^* \end{aligned}$$

and, hence, in order to preserve the convergence of the integral

$$\begin{aligned} \varphi(x, y) = & \frac{U}{2\pi\beta} \int_{-c/2}^{c/2} \theta_a(x^*) \int_0^{\infty} \left\{ \frac{e^{-\beta y\mu}}{\mu} [1 - \cos \mu(x^*-x)] \right. \\ & \left. - \left[\frac{e^{-\beta y\mu} - e^{-\beta h\mu}}{\mu} \right] + \frac{e^{-\beta h\mu}}{\mu} \left[1 + \frac{(\mu - \lambda) \cosh(\beta y\mu) \cos \mu(x^*-x)}{\mu \sinh(\beta h\mu) + \lambda \cosh(\beta h\mu)} \right] \right\} d\mu dx^*. \quad (20) \end{aligned}$$

Using the results (e.g. Edwards (1922), p. 213) that

$$\int_0^{\infty} \frac{e^{-qx} - e^{-px}}{x} \cos bx \, dx = \frac{1}{2} \log \left\{ \frac{p^2 + b^2}{q^2 + b^2} \right\}$$

and

$$\int_0^{\infty} e^{-ax} \frac{\cos px - \cos qx}{x} dx = \frac{1}{2} \log \left\{ \frac{a^2 + q^2}{a^2 + p^2} \right\},$$

equation (20) becomes

$$\varphi(x, y) = \frac{U}{\pi\beta} \int_{-c/2}^{c/2} \theta_a(x^*) \left\{ \frac{1}{2} \log [(x^*-x)^2 + \beta^2 y^2] - \log \beta h - I([x^*-x], y) \right\} dx^* \quad (21)$$

where

$$I([x^*-x], y) = \int_0^{\infty} \frac{e^{-\beta h\mu}}{\mu} \left\{ 1 + \frac{(\mu - \lambda) \cosh(\beta y\mu) \cos([x^*-x]\mu)}{\mu \sinh(\beta h\mu) + \lambda \cosh(\beta h\mu)} \right\} d\mu. \quad (22)$$

From (7),

$$\int_{-c/2}^{c/2} \theta_a(x^*) dx^* = \frac{\delta}{2}, \quad (23)$$

where δ is the thickness of solid sting of the wake, so that, on integrating by parts, (21) gives

$$\varphi(x, y) = \frac{U\delta}{2\pi\beta} \left\{ \frac{1}{2} \log \left(\left[\frac{c}{2} - x \right]^2 + \beta^2 y^2 \right) - \log(\beta h) - I \left(\left[\frac{c}{2} - x \right], y \right) \right. \\ \left. - \frac{U}{\pi\beta} \int_{-c/2}^{c/2} y_a(x^*) \frac{x^* - x}{[x^* - x]^2 + \beta^2 y^2} - I'_{x^*}([x^* - x], y) \right\} dx^*, \quad \dots \quad (24)$$

where $I'_{x^*} = \frac{\partial I}{\partial x^*}$. (25)

The solution of the boundary value problem defined by equations (5), (8) and (9), $\Phi(x, y)$, say, is clearly of the form

$$\Phi(x, y) = \varphi(x, y) + C \quad \dots \quad (26)$$

where $\varphi(x, y)$ is given by (24) and C is a constant. The appropriate value of C can be found from the condition that the limit, as $h \rightarrow \infty$, of $\Phi(x, y)$ exists. That is, from (22), (23) and (25),

$$C = \frac{U\delta}{2\pi\beta} \log(\beta h), \quad \dots \quad (27)$$

so that we may write

$$\varphi(x, y) = \frac{U\delta}{2\pi\beta} \left\{ \frac{1}{2} \log \left(\left[\frac{c}{2} - x \right]^2 + \beta^2 y^2 \right) - I \left(\left[\frac{c}{2} - x \right], y \right) \right\} \\ - \frac{U}{\pi\beta} \int_{-c/2}^{c/2} y_a(x^*) \left\{ \frac{x^* - x}{[x^* - x]^2 + \beta^2 y^2} - I'_{x^*}([x^* - x], y) \right\} dx^* \quad \dots \quad (28)$$

where $\varphi(x, y)$ has been written, without ambiguity, for $\Phi(x, y)$.

5. The Blockage Factor

The value of φ pertaining to an aerofoil in a free stream, φ^* , is obtained from (28) by taking the limit $h \rightarrow \infty$; thus,

$$\varphi^*(x, y) = \frac{U}{2\pi\beta} \left\{ \frac{\delta}{2} \log \left(\left[\frac{c}{2} - x \right]^2 + \beta^2 y^2 \right) - 2 \int_{-c/2}^{c/2} y_a(x^*) \frac{x^* - x}{[x^* - x]^2 + \beta^2 y^2} dx^* \right\}. \quad \dots \quad (29)$$

The increment to the perturbation potential due to the presence of the tunnel walls is then given by

$$\varphi(x, y) - \varphi^*(x, y) = \frac{-U}{2\pi\beta} \left\{ \delta I \left(\left[\frac{c}{2} - x \right], y \right) - 2 \int_{-c/2}^{c/2} y_a(x^*) I'_{x^*}([x^* - x], y) dx^* \right\}. \quad \dots \quad (30)$$

Therefore, from (3),

$$\epsilon = \frac{-1}{2\pi\beta} \left\{ \delta I'_{x^*} \left(\left[\frac{c}{2} - x \right], y \right) - 2 \int_{-c/2}^{c/2} y_a(x^*) I''_{x^*x}([x^* - x], y) dx^* \right\}. \quad \dots \quad (31)$$

Since the blockage factor is defined for points on the aerofoil surface it follows that, for a slender aerofoil, we may take $y=0$. A further simplification can be obtained by assuming that $\frac{c}{\beta h} < 1$ (an assumption consistent with practical wind-tunnel investigations) so that terms of higher order than $\left(\frac{c}{\beta h}\right)^2$ may be ignored. The determination of the blockage factor then depends on the evaluation of the functions $I'_{x^*} \left(\left[\frac{c}{2} - x \right], 0 \right)$ and $I''_{x^*x}([x^* - x], 0)$.

To this end, we put

and

$$\left. \begin{aligned} p &= \beta h \mu \\ a &= \frac{x^* - x}{\beta h} \end{aligned} \right\} \dots\dots\dots (32)$$

in equation (22). That is,

$$I(a) = \int_0^\infty \frac{e^{-p}}{p} \left\{ 1 + \frac{(p - \beta h \lambda) \cos(ap)}{p \sinh p + \beta h \lambda \cosh p} \right\} dp. \dots\dots\dots (33)$$

The derivatives, of all orders, with respect to a of $I(a)$, as given by (33), are uniformly convergent so that we may write

$$I(a) = I(0) + aI'(0) + \frac{a^2}{2}I''(0) + O(a^3) \dots\dots\dots (34)$$

where $I^{(n)}(a) = \frac{d^n}{da^n} \{I(a)\}$.

From (33),

$$\begin{aligned} I(0) &= \int_0^\infty \frac{e^{-p}}{p} \left\{ 1 + \frac{p - \beta h \lambda}{p \sinh p + \beta h \lambda \cosh p} \right\} dp, \\ I^{(2n)}(0) &= (-1)^n \int_0^\infty \frac{p^{2n-1} e^{-p} (p - \beta h \lambda)}{p \sinh p + \beta h \lambda \cosh p} dp, \quad n=1, 2, \dots\dots\dots (35) \end{aligned}$$

and

$$I^{(2n-1)}(0) = 0, \quad n=1, 2, \dots\dots\dots (36)$$

Equation (34) becomes, using (22), (32) and (36),

$$I([x^* - x], 0) = I(0) + \frac{(x^* - x)^2}{2\beta^2 h^2} I''(0),$$

to second order in $\frac{x^* - x}{\beta h}$, and therefore

$$I'_x \left(\left[\frac{c}{2} - x \right], 0 \right) = - \frac{\frac{c}{2} - x}{\beta^2 h^2} I''(0) \dots\dots\dots (37)$$

and

$$I''_{xx} \left(\left[\frac{c}{2} - x \right], 0 \right) = - \frac{1}{\beta^2 h^2} I''(0). \dots\dots\dots (38)$$

From (35), it can be seen that $I''(0)$ converges uniformly for $\lambda \geq 0$.

Substituting (37) and (38) in (31) we have that

$$\varepsilon = \frac{1}{2\pi\beta^3 h^2} \left\{ \left[\frac{c}{2} - x \right] \delta - A_e \right\} I''(0), \dots\dots\dots (39)$$

where A_e is the area of cross-section of the aerofoil and $I''(0)$ is given by (35). Equation (39) is identical with that obtained by Woods (1961) and is in agreement with the results of the other investigators.

The more usual form for the blockage factor can be obtained by using the relation between the thickness of the wake, δ , and the drag, D , on the aerofoil, namely (Robinson and Laurmann, 1956, p. 161),

$$\delta = \frac{D}{\rho U^2}. \dots\dots\dots (40)$$

Defining the drag coefficient, C_D , by the equation

$$C_D = \frac{D}{\frac{1}{2}\rho U^2 c} \dots\dots\dots (41)$$

we have, from (40) and (41),

$$\delta = \frac{cC_D}{2} \dots\dots\dots (42)$$

Therefore, from (39) and (42),

$$\epsilon = \frac{1}{2\pi\beta^3 h^2} \left\{ \frac{cC_D \left[\frac{c}{2} - x \right]}{2} - A_e \right\} I''(0) \dots\dots\dots (43)$$

6. Evaluation of the Blockage Factor

For the evaluation of the blockage factor in a particular tunnel, the value of $I''(0)$ is required and the value of this function, in turn, depends, as can be seen from (35), on the parameter λ appropriate to the tunnel. It is, therefore, convenient to obtain a series expansion for $I''(0)$ to enable calculation of its value for any value of λ (≥ 0).

An expansion can be obtained by writing (35) in the form

$$I''(0) = -2 \lim_{v \rightarrow 0} \int_v^\infty p e^{-2p} \left[\frac{p - \beta h \lambda}{p + \beta h \lambda} \right] \left[1 + \left(\frac{p - \beta h \lambda}{p + \beta h \lambda} \right) e^{-2p} + \dots \right. \\ \left. + \left(\frac{p - h}{p + h} \right)^n e^{-2np} + \dots \right] dp.$$

This becomes, on letting $q = p + \beta h \lambda$,

$$I''(0) = -2e^{2\beta h \lambda} \lim_{v \rightarrow 0} \int_{v + \beta h \lambda}^\infty q e^{-2q} \left(1 - \frac{\beta h \lambda}{q} \right) \left(1 - \frac{2\beta h \lambda}{q} \right) \\ \left[1 + \left(1 - \frac{2\beta h \lambda}{q} \right) e^{2\beta h \lambda} e^{-2q} + \dots \right. \\ \left. + \left(1 - \frac{2\beta h \lambda}{q} \right)^n e^{2n\beta h \lambda} e^{-2nq} + \dots \right] dq \dots\dots (44)$$

Equation (44) may be expressed in terms of the incomplete Gamma function $\Gamma(a, x)$ defined by (Erdelyi, 1953, p. 266)

$$\Gamma(a, x) = \int_x^\infty e^{-t} t^{a-1} dt, \dots\dots\dots (45)$$

and we find

$$I''(0) = -2e^{2\beta h \lambda} \sum_{n=0}^\infty \left\{ \frac{1}{2^2} \frac{\Gamma(2, 2(n+1)\beta h \lambda)}{(n+1)^2} \right. \\ \left. + \sum_{r=1}^{n+2} 2^{2r-3} (n+1)^{r-2} (2n-r+4) \frac{(n+1)n \dots (n-r+3)}{r!} (-\beta h \lambda)^r \right. \\ \left. \Gamma(2-r, 2(n+1)\beta h \lambda) \right\} \dots\dots\dots (46)$$

From (45) it is easily shown that

$$(i) \quad \Gamma(a, x) = x^{a-1}e^{-x} + (a-1)\Gamma(a-1, x) \quad a=2, 3, 4, \dots;$$

$$(ii) \quad \Gamma(1, x) = e^{-x};$$

$$(iii) \quad \Gamma(-a, x) = \frac{e^{-x}}{ax^a} - \frac{1}{a}\Gamma(-(a-1), x) \quad a=1, 2, 3, \dots;$$

and, by definition (Erdelyi, op. cit., p. 267),

$$(iv) \quad \Gamma(0, x) = -E_i(-x),$$

where $-E_i(-x)$ is the exponential integral. These four properties, together with (46), allow the determination of $I''(0)$ from tabulated functions.

7. Special Values of the Slot Parameter

With completely open walls $A=0$ (see, for example, Woods (1961)) so that from (15) $\lambda=\infty$. Using the result (Erdelyi, op. cit., p. 278) that, for large $|x|$,

$$\Gamma(2-r, x) = e^{-x} \sum_{n=0}^N \frac{(-1)^n (r-1)_n}{n!} x^{1-r-n} + O(|x|^{-r-n-N}) \quad N=0, 1, 2, \dots \quad (47)$$

where $(r-1)_n = \frac{\Gamma(r+n-1)}{\Gamma(r-1)}$, equations (46) and (47) yield

$$I''(0) = \frac{1}{2} \sum_{n=1}^{\infty} \left\{ (-1)^{n-1} \frac{1}{n^2} \right\}.$$

That is,

$$I''(0) = \frac{\pi^2}{24}. \quad (48)$$

Substituting (48) in (43) gives the well-known result for the blockage in an open wind-tunnel (Woods, 1955)

$$\varepsilon = -\frac{\pi c C_D}{96\beta^3 h^2} \left(x - \frac{c}{2} \right) - \frac{\pi A_e}{48\beta^3 h^2}.$$

For a completely closed (solid wall) wind-tunnel $A=\infty$ and $\lambda=0$. Equation (46) gives, in this case,

$$I''(0) = 1 - \frac{1}{2} \sum_{n=1}^{\infty} \left\{ \frac{1}{n^2} \right\} = -\frac{\pi^2}{12}.$$

Substituting this value in (43) we find

$$\varepsilon = \frac{\pi c C_D}{48\beta^3 h^2} \left(x - \frac{c}{2} \right) + \frac{\pi A_e}{24\beta^3 h^2}.$$

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Zircons in Some Granites from North-Western Queensland

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Introduction

Nine Precambrian granitic bodies have been mapped and formally named in North-western Queensland (Carter, Brooks and Walker, 1961), and though most of them are probably magmatic granites, Joplin and Walker (1961) have suggested that the southern end of the Wonga Granite, north of Duchess, and a part of the Sybella Granite, near Waverley Creek, have a metasomatic origin.

Poldervaart (1950) has suggested that statistical studies of zircon in granites might prove useful as a criterion in distinguishing magmatic and metasomatic granites, and it was decided to apply this method to the granites of North-western Queensland. The work was commenced by Abbott, whilst working as a vacation student at the Australian National University. He examined a number of specimens of the Kalkadoon Granite, and as this gave promising results it was decided to continue with other specimens.

Measurements of zircon, according to methods used by Poldervaart (1955, 1956), were then continued by Rudowski, but before much work had been done, all Abbott's results and most of the granite specimens from this area were lost in a fire. However, we continued with the limited material that was available, and as our results appear to have some significance and we are unlikely to do further collecting in this area, we present them in the hope that they may prove of some use to those who may consider it worth while continuing with this study.

Of the nine granitic masses mapped and named our specimens come from only four, there being only a single specimen of three of them and three specimens of the Kalkadoon Granite. One of the specimens from an area mapped as Kalkadoon Granite (K_2) comes from a mass that Joplin and Walker (1961) have suggested may be a southern continuation of the Wonga Granite.

The specimens examined for zircon come from:

The Kalkadoon
Granite

(K_1)

(K_2)

(K_3)

Duchess-Dajarra Road. 17 miles south-west of Duchess and 3.8 miles south-west of Butru Railway Siding. 20 miles south of Duchess and 11 miles from Mayfield Homestead. Kurbayia Railway Siding, Mt. Isa-Duchess Road, 22 miles from Mt. Isa.

The Williams
Granite

The Naraku
Granite

27 miles east-south-east of Selwyn, North McKinlay River. Police Water Hole, Urquhart Creek, about 5 miles south-east of Quamby on Quamby-Cloncurry Road, 22 miles from Cloncurry.

The Wonga
Granite

8 miles north of Duchess and east of Lady Fanny Mine.

Separation and Mounting

About 3,000 gm. of each specimen were crushed in a jaw crusher, and then ground to pass through a 100 mesh B.S.S. sieve, and about 200 gm. of each was then superpanned. From each of these, three concentrates were obtained, and each was treated separately on an isodynamic separator, and finally concentrated by boiling in concentrated hydrochloric acid.

Aliquot parts of the three fractions, so obtained, were separately mounted in Lakeside cement, and the best mount, that contained at least 300 zircons, was selected for measurement.

This method of separation gave a high degree of purity (about 90%), and in most samples 300 zircons could be found quite readily.

Observations and Measurements

Observations were made on colour, inclusions, zoning, crystal form and perfection, overgrowths and rounding; and measurements were made on length and breadth.

In all six specimens examined most of the zircons were colourless or light yellow though many of these were clouded with dark fibrous

inclusions. No hyacinths nor malacons were observed, though a few light brown zircons were present in most specimens, the Kalkadoon Granite (K_1) containing 12 of the 300 zircons observed, the Williams Granite 11, and the others less.

Zoning is a very common feature and with the exception of the Wonga Granite, unzoned zircons are in the minority. The Wonga Granite contained 45% zoned, the Kalkadoon (K_1) 53% zoned and the percentage of zoned crystals in the other granites ranged from 70-90%.

In all specimens zircons showed perfect crystallization and no corrosion. A large number of the zircons are prismatic and bi-pyramidal, but many also show a basal pinacoid and have only one pyramidal termination.

Overgrowths are not common, but from 2% to 3% have been observed among the zircons of each specimen examined.

As may be seen in the following table rounding of the zircons is present in all specimens, but is most prominent in the Wonga Granite (see also Fig. 1).

	On pyramidal termination	On all crystal edges	Ovoids	Spheres
Kalkadoon Granite				
(1)	65	—	14	—
(2)	155	—	19	—
(3)	64	1	34	—
Williams Granite	105	2	25	—
Naraku Granite ..	87	6	22	—
Wonga Granite ..	106	4	134	3

Reference to Figs. 2 and 3 will show that the elongation ratio of unsorted zircons is approximately 2 in the case of the Kalkadoon Granites (1) and (2) and slightly over 2 in the Williams Granite, but in the Naraku, Kalkadoon (3) and Wonga Granites the maximum lies between 1 and 2; moreover in these same three granites the histograms (Fig. 3) show that the maxima of the different length ranges are almost co-incident, whereas they differ slightly in the William and Kalkadoon (1) and (2) Granites.

Further, reference to Fig. 3 will show that the length range, c , 0.004-0.06 mm, is the most common in all granites except the Wonga, and in the Naraku and Kalkadoon (1) and (2) Granites the length d , 0.06-0.08 mm, is the next most common. The range b , 0.02-0.04 mm, is present only in the Kalkadoon (3), Naraku

and Williams Granites and though only a very small number of crystals ranging in length from 0.12-0.4 mm (i.e. g) are present in all granites, this length of crystal is relatively common in the Wonga Granite. Furthermore, the Wonga Granite contains a number of

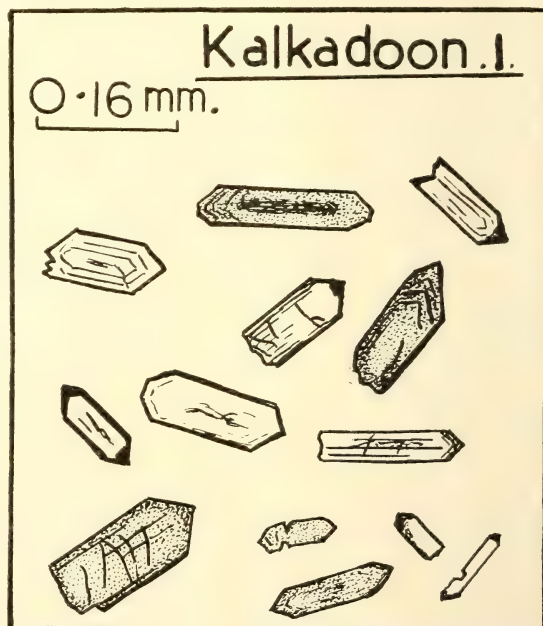
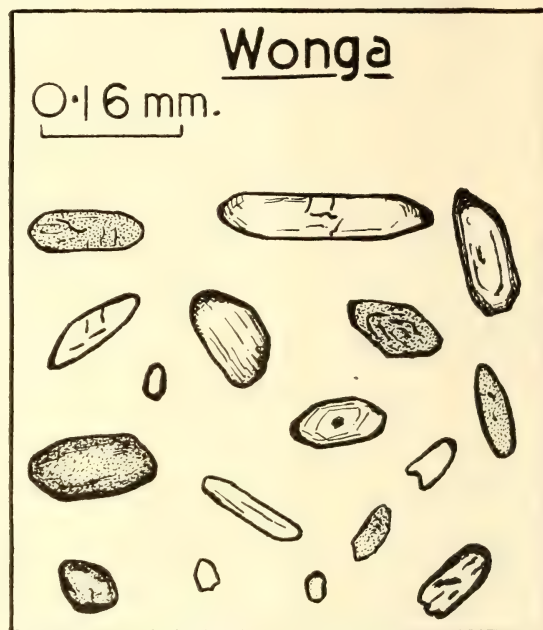


FIG. 1
Zircons from two granites showing differences in rounding of crystals.

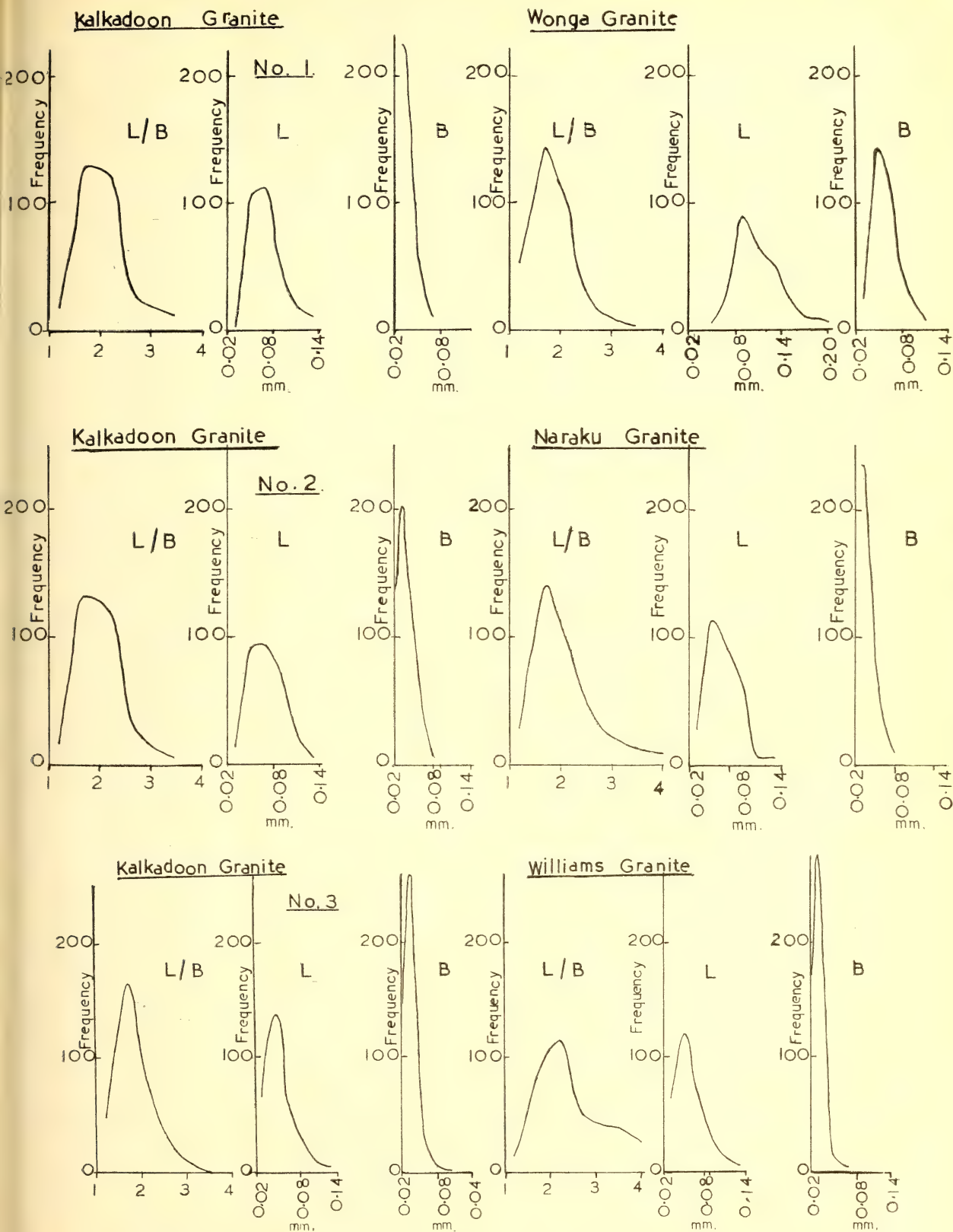


FIG. 2

Zircon size frequency curves.

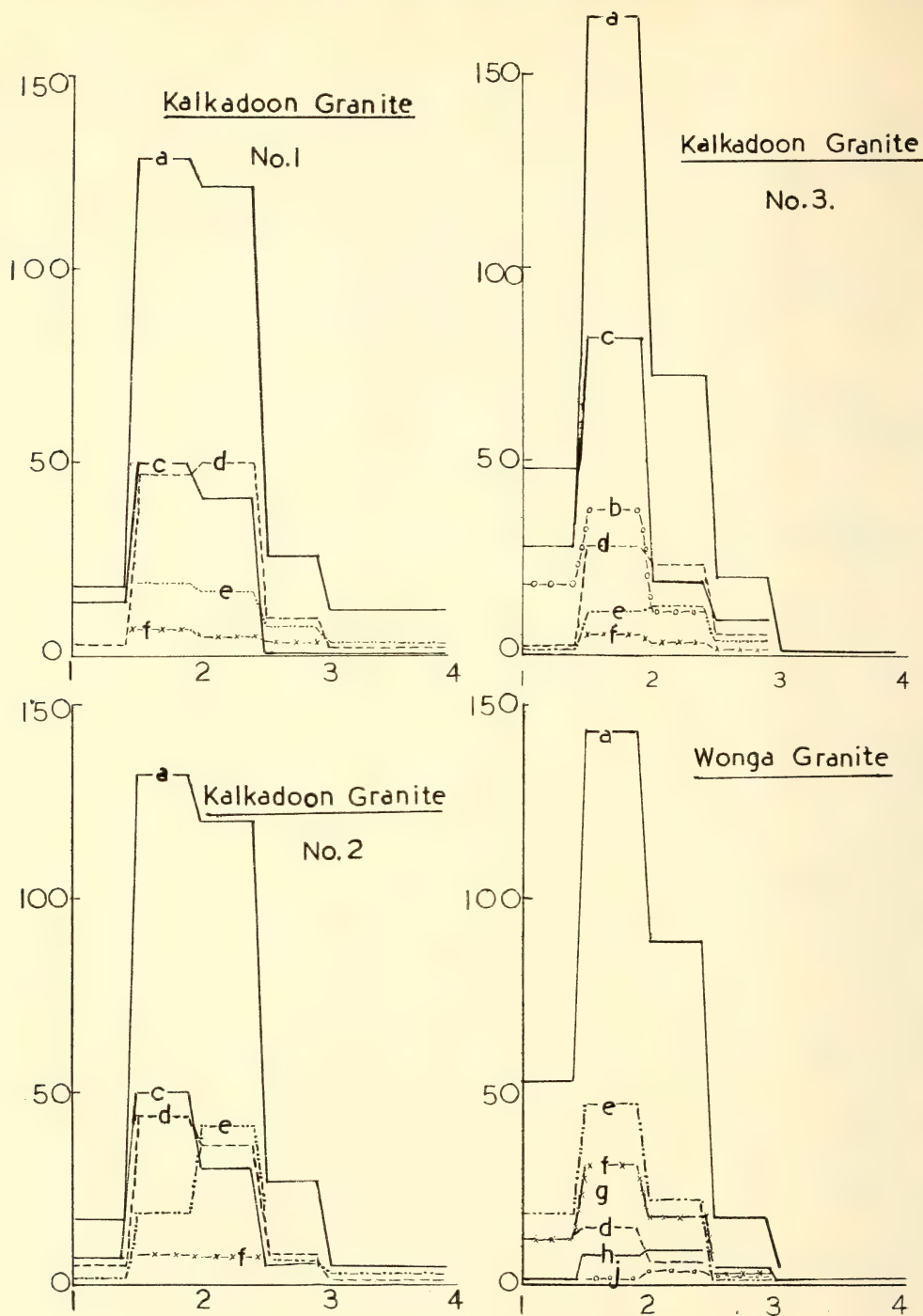


FIG. 3

Histograms showing elongation ratios of crystals of different length ranges.

a—unsorted crystals,
c—(0.04–0.06 mm),
e—(0.08–0.10 mm),
g—(0.12–0.14 mm),
i—(0.16–0.18 mm),

b—(0.02–0.04 mm),
d—(0.06–0.08 mm),
f—(0.10–0.12 mm),
h—(0.14–0.16 mm),
j—(0.18–0.20 mm).

The range “*g*” occurs in all granites, but as there are very few crystals of this size in all granites, except the Wonga, these curves have been omitted for the sake of clarity; similarly the size range “*i*” has been omitted in the histogram of the Wonga Granite.

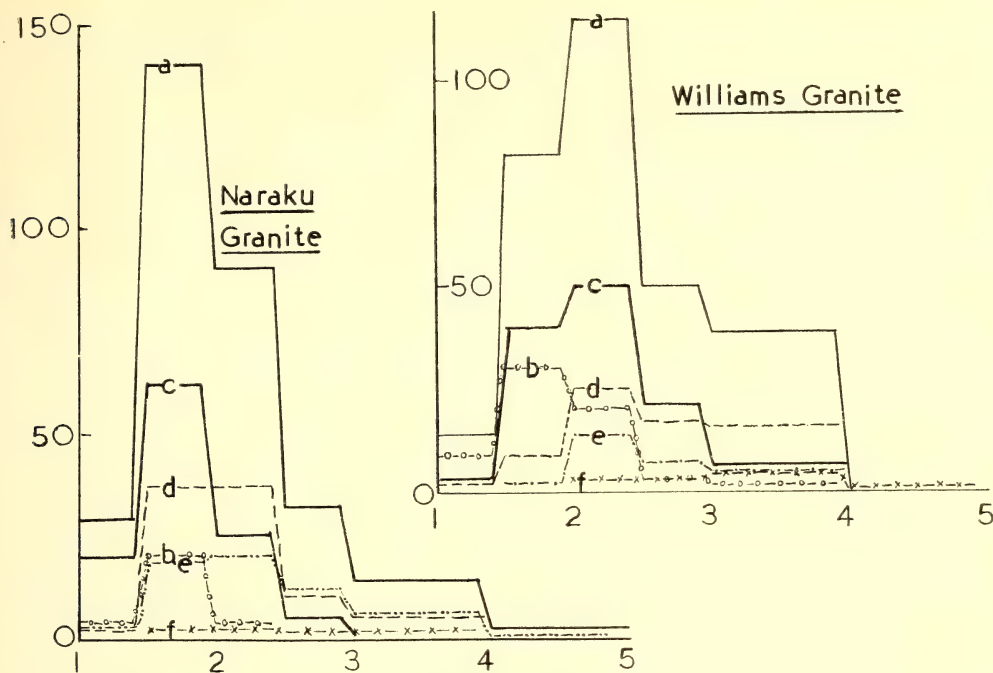


Fig. 3—continued

crystals of still greater length ranging from *h*, 0.14–0.16 mm, *i*, 0.16–0.18 mm, and *j*, 0.18–0.20 mm.

Conclusion

This work is only a beginning to the study of zircons in the granites of North-western Queensland and no final conclusions can be reached.

It can be pointed out, however, that the elongation ratio seems to suggest that some of the zircons in the Wonga, Naraku and Kalkadoon (3) Granites may be of sedimentary origin, and that this ratio might be even lower in the Wonga Granite had not the original zircons been so elongated. Furthermore, it is shown that the Wonga Granite differs from the others in containing these elongated zircons and also in containing a fewer number of zoned zircons.

The Kalkadoon Granites (1) and (2) are very similar, yet (2) comes from an area that

Joplin and Walker (1961) believe to be Wonga Granite. Their assumption was based on the examination of a number of slides and several modal analyses, and though the idea cannot be outruled by the examination of zircon in a single specimen, it is obvious that this area should be more closely examined.

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A Note on Stratigraphical Nomenclature-- Biostratigraphic Zones and Time-Rock Stages

K. A. W. CROOK

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Stratigraphy in Australia took a valuable step forward with the general recognition that rock units differed fundamentally from time-rock units. The value of recognizing a similar distinction between biostratigraphic and time-rock units deserves consideration.

In this connection Chappell's recent treatment (Chappell, 1961) of part of the Tamworth Group, in which he erects three biostratigraphic units which he terms "stages", is most thought-provoking.

The Australian Code of Stratigraphic Nomenclature (1959), which defines "stage" as a time-rock unit, devotes only four lines to biostratigraphic units (zones), under the heading "Time and Time-Rock Units", in which no clear definition of a biostratigraphic unit is given. This perhaps reflects a tendency among Australians to think that biostratigraphic zones and time-rock stages are virtually synonymous—for are not the Ordovician graptolite zones of Victoria used to subdivide the Ordovician System into Series and Stages?

If this virtual identity between time-rock units (stages) and biostratigraphic units (zones) were true in every case, there would be no cause for concern. However, the virtual identity in the case cited above is accidental, and depends on the graptolite zones being zones of the "time-concordant" type. There are other zones, mostly of local significance, which are ecologically controlled and are time-transgressive (Young, 1959).

A biostratigraphic unit is to the palaeontology of a sequence what a lithostratigraphic (rock) unit is to its lithology: a mappable, objective unit without any necessary time connotation. A time-rock unit, although delimited by biostratigraphic units, involves a subjective judgement that the biostratigraphic units are of the "time-concordant" type.

Our knowledge of the faunas of the Tamworth Group is not yet sufficiently detailed to enable a judgement to be made in the case of the units

Chappell has termed "stages". The term "assemblage-zone" (American Code, 1961) would seem more apt for these entities, and would eliminate the possibility of confusion which the time-connotation of "stage" might cause.

An expansion of the article on zones in the Australian Code would seem highly desirable. This could define biostratigraphic units, describing the various varieties, and could distinguish them from time-rock units.

The terms "Moore Creek Limestone", "Sulcor Limestone", "Loomberah Limestone" and "Nemingha Limestone" were originally proposed for rock-units, although they were distinguished from each other chiefly on palaeontological grounds. Later work enabled the recognition of three of them (all but Sulcor Limestone) by their stratigraphic positions, and these three are now formally defined rock units (Crook, 1961). Their usage in Chappell's area, in those places where neither mappable continuity with the type sections nor similarity of position within a recognized sequence can be established, should in my opinion be considered informal, as it involves a confusion between lithostratigraphic (rock unit) correlation and biostratigraphic correlation.

Units correlated stratigraphically *solely* on the basis of fossils should not bear the same rock unit names; they should share a biostratigraphic unit name. Thus the obvious faunal relationships between the limestones in the Tamworth Group should be expressed by referring them to appropriate "assemblage zones".

The faunal assemblages recognized by Hill (1942) make available a basis for such a nomenclature. Thus the limestones encompassed by the names "Moore Creek Limestone Member", "Crawney Limestone Member" and "Timor Limestone" (Crook, 1961) and "Moore Creek Stage" (Chappell, 1961), along with any other unnamed limestones bearing the same fauna,

should, I consider, be described formally as "Limestones of the *Sanidophyllum davidis* Assemblage Zone", rather than as "Moore Creek limestones".

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Lawrence Hargrave—An Appreciation*

W. HUDSON SHAW

Qantas Empire Airways, Ltd., Sydney

Tonight we are concerned with the past, so I want you to step with me into the time machine and travel back into the middle of the last century to enable us to picture the background essential to our story and better understand the difficulties and so make a more reasonable judgment of the events.

Victorian England is in its heyday. The middle class has come into its own. Their splendidly equipped riders and carriages crowd the roads. The horse is still the chief medium of transport, but the railways are beginning to take over. The motor car is fifty years away. The candle is the main light source. On the Thames, some miles from London, lies Greenwich, made famous by Samuel Pepys and Christopher Wren, and our journey ends at a rather severe Georgian house on a grey day, the 29th of January in the year 1850. We arrive just in time to hear the cries of a new-born child. Lawrence Hargrave's career has begun.

He comes from a long line of Yorkshiremen who are thought to have come to England from Holland in the seventeenth century. His father is a London barrister. Shortly after Lawrence is born, the Hargraves move to nearby Otford. In 1856, doctors advise Lawrence's father to go to Australia for health reasons. That he decided to stay on after his recovery and became a prominent judge and one of the giants of the early political life of N.S.W. is another story.

Lawrence, at the age of 16, decided to follow his father and arrived in N.S.W. in 1866. The judge proposed a law course for his son, and after about a year's study and a failure to matriculate, it was decided that his future lay elsewhere. In 1868 we find him in the drawing office and later in the workshops of the Australian Steam Navigation Company, where, for the next four years, he learned much that was to be

fundamental in his future career. He, in the company of 75 other young men of Sydney town, in 1872 chartered the unseaworthy brig *Maria* to search for fame and fortune in New Guinea. The wreck of this ship on the Barrier Reef and his part in two other New Guinea expeditions is yet another story.

1877 and 1878 were important years for young Hargrave as they saw him settling down in a steady job with the Sydney Observatory, become a member of the Royal Society of N.S.W. and his marriage to Margaret Preston Johnston. For many years Hargrave had been thinking deeply about the possibility of human flight. The thought was probably born by his observations of the albatross encountered in the "Roaring Forties" on his voyage out from England. It is known that he devoted a good deal of his spare time to watching bird flight and also the study of the movement of snakes, fishes and ocean waves. This study resulted, in 1882, in the production of his famous Trochoidal Theory of Serpentine propulsion.

A year later he made the important decision to devote his life's work to the conquest of the air, and as he then had sufficient income to be self-supporting, he resigned from the Observatory. His first paper on the Trochoidal Plane was read to the Royal Society of N.S.W. in 1884.

Judge Hargrave, Lawrence's father, passed away after a prolonged illness in 1885. In this year, Lawrence built his first home, a block of three terrace houses with four floors in Rushcutter's Bay Road. He occupied No. 40 and it was from this home that all his important work on model aeroplanes was carried out. The terrace is still standing, but the street has been renamed Roslyn Gardens. In 1892 his only son, Geoffrey, was born, and the following year the family, consisting of four daughters, son, nurse and governess, moved to Stanwell Park to a house left to him by his brother, Ralph. This move was made partly to reduce expenses, partly to obtain steady winds and

* Address delivered before the Royal Society of New South Wales, 5 December, 1962. Opinions expressed are not necessarily those of Qantas Empire Airways, Ltd.

permit experiments into supporting surfaces to be made without interruption from the public.

It was at Stanwell Park that the famous Box Kite was conceived and developed in 1893.

The whole family left for England in February, 1899. High costs, lack of opportunity and interest in his work caused them to return to Sydney after a stay of only six months. The family, now growing up, were no longer prepared to accept the isolation of Stanwell Park, so they occupied another of the terraces in Roslyn Gardens, this time No. 44. Hargrave's experiments were well into the third stage of engine development so that the decision to live in Sydney had some advantages as materials and foundries were close at hand. It meant, however, a most unfortunate rise in living costs.

Hargrave was still hopeful that he would soon be building a full-size aeroplane. As flight trials were to be made on water, the land at the end of Woollahra Point was acquired for this purpose and a house of three floors built and occupied in 1902. The house is still standing near the end of Wunulla Road, Point Piper, and apart from being converted into two flats is little changed.

The period which followed was undoubtedly the most frustrating of his whole life. His continuing efforts to produce a satisfactory engine were unsuccessful. His carefully considered and well supported theory that the Spaniards had discovered the east coast of Australia in 1595 was ridiculed. Unfortunately, time does not permit me to more than mention this fascinating subject tonight. His plan for the Port of Sydney appears to have been ignored. His only son, Geoffrey, was killed in action at Gallipoli on the 24th May, 1915. Lawrence Hargrave passed away two months later, on the 16th July, at Lister Hospital, as a result of acute peritonitis.

I hope that this brief background will assist in your understanding of the events I am about to relate, which have been arranged in the following order :

- (1) A series of slides showing Hargrave's major inventions in chronological order.
- (2) Some brief references to his work and association with your Society.
- (3) Highlights of his aeronautical work.
- (4) Background on personality.
- (5) His attitude to his work and patents.
- (6) Some inconsistencies.
- (7) Clearing up some misunderstandings.
- (8) Vision.
- (9) His place in aeronautical history.

Major Inventions

The following slides have been made from Hargrave's records to provide some idea of his achievements :

Slide

- | | | |
|--|-------|------|
| 1. Shoes for walking on water | .. | 1870 |
| 2. One-wheel velocipede | .. .. | 1871 |
| 3. Screw-driven airship | .. .. | 1872 |
| 4. Mechanical snakes | .. .. | 1882 |
| 5. Trochoided boats | .. .. | 1883 |
| 6. Manpower operated flapper test unit | .. .. | 1887 |
| 7. First propeller driven flying machine | | 1888 |
| 8. Three cylinder radial engine | .. | 1889 |
| 9. Wave-propelled vessel | .. .. | 1891 |
| 10. Some early model flying machines | | 1893 |
| 11. First box kite designs | .. .. | 1893 |
| 12. First full size monoplane-glider | .. | 1894 |
| 13. Design of steam turbine for an aeroplane | .. .. | 1895 |
| 14. Jet propeller engine—steam | .. | 1895 |
| 15. Second design for full size powered aeroplane—on floats | .. .. | 1896 |
| 16. Third design for full size powered aeroplane—on floats | .. .. | 1902 |
| 17. Compressed air motor contra rotating propellers quatre plane | .. | 1904 |
| 18. 18-foot steel hulled boat | .. .. | 1906 |
| 19. Design for deep water port, Sydney | | 1906 |
| 20. One wheel car | .. .. | 1907 |

Royal Society

Lawrence Hargrave became a member of the Royal Society of N.S.W. in 1877 and contributed the remarkable total of 24 papers. The papers were printed and sent to many parts of the world and were largely responsible for Hargrave's work being known in other countries.

It is indeed a pity that a contemporary account does not exist of members' reactions to a Hargrave lecture. Newspaper cuttings of the time do not do justice to these sometimes exciting occasions. Perhaps we can picture the scene in "The Society's House" with the small hall filled with serious, bewhiskered gentlemen. Hargrave's report of one such occasion concludes : "I will now wind up the machines and let them speak for themselves... if one of them threatens to strike any gentleman present, would he kindly hold up his hands—so—this will stop the flight and the machine will fall harmlessly to the ground."

Aeronautical Work—Model Period

I think it would be safe to say that this was the most productive and satisfying period of Hargrave's aeronautical experiments. Work

commenced in earnest in 1883 and was spread over ten years. During the majority of this time, aviation experiments elsewhere were at a standstill. Even if it cannot be said with any certainty that the success of Hargrave's experiments triggered off the important work of Lilenthal, Pilcher and Chanute in the '90's, it is certain that they gained a great deal of encouragement from his work and his unselfish sharing of his discoveries.

The record is an impressive one. Hargrave demonstrated conclusively the practicability of flight by designing and building of some 50 model flying machines up to 10 feet in length. The majority of these machines were powered by india rubber on a most ingenious and original principle and obtained their thrust from flapping wings. The movement of the wings represented the mechanical reproduction of his conception of the action of a bird's wing in flight—the trochoical principle discovered in 1882.

He stated his case for flappers on the 1st June 1892, as follows :

1. Currents initiated by the up stroke increase the efficiency for the down stroke.
2. Only one cylinder needed for both flappers. (Referring, of course, to a compressed air motor.)
3. No tendency to veer.
4. Less liability to damage on landing.

His first steam engine was built in 1888, but this was not a success. Then followed a number of different types of compressed air engines of ingenious design. The hollow wooden spar which formed the body of the elastic powered machines gave way to a lightweight metal tube which also formed the container for the compressed air. Engine cylinders were made of tin and were of single and triple cylinder types. His famous three-cylinder radial rotary engine was invented in 1889.

The greatest distance flown by an elastic powered machine was 270 feet, and 368 feet by a compressed air model.

Difficulties in experimentation are indicated by the following extract from a letter dated 8th December, 1891 : "No. 16 has just been tried and wrecked for the 5th time, there was a terrible smash ; however, no real advance can be made without flying the machine free so I plod on with renewed stubbornness."

At the conclusion of a paper to this Society on 1st July, 1891, Hargrave said : "It may be said that it is a waste of time to make machines of such small capacities and no practicable good can come of them. But we must not try too much at first, we must remember that all our inventions are but developments of crude ideas,

that a commercially successful result in a practically unexplored field cannot possibly be got without an enormous amount of unremunerative work."

One of the many interesting developments of this period was the chronograph designed and built by Hargrave to make simultaneous recordings on a chart, of time in seconds, flapper vibrations and air pressure. Many other devices were built for testing purposes.

A vital consideration in all Hargrave's aeronautical work was lightness. He expressed his philosophy on this subject to your Society in June, 1890, in these words : "It should be remembered that flying machines are only to battle with the air and not for knocking down fences or ploughing up the ground. It is not usual to proportion the plating of ships so that they will stand beating on the rocks, but only to safely resist the strains produced by the wind and the waves. Perhaps much of the writer's success has been due to the avoidance of this fault, although it is somewhat of a trial to see a month's work knocked out of all shape in a moment."

There was a sharp division of opinion amongst the earlier experimenters on the subject of weight which may seem strange to us today.

Aeronautical Work—Supporting Surfaces

I quote from paper to Royal Society, 7th June, 1893 :

"Before beginning another motor, it was thought advisable to try whether a better disposition of supporting surfaces could be found and at the same time see if any foundation could be discovered for the assertion that birds utilised the wind in soaring. No amount of observation of birds will solve the soaring problem. It can only be done by making some form of soaring apparatus that will advance against the wind without losing its elevation."

He thought the expense of constructing a large whirling arm machine too great and it would not produce true conditions. He considered kites as best means towards the desired end. He knew that the experience of Wenham, Philips and others favoured superimposed planes for supporting surfaces.

The first box kite was produced on 15th February, 1893, and made of circular cells. The following day a square celled box kite was constructed. This was the true ancestor of the more sophisticated box kites, four of which lifted Hargrave 16 feet off the ground on 12th November, 1893. As a result of this experiment, Hargrave stated that there is no limit to the weight that may be buoyed up in a breeze. The exhibits in the hall include models of the

squared cell kite and the standard box kite eventually evolved from it.

When Hargrave received news of Lilenthal's successful gliding experiments, he constructed a full size monoplane glider with the same wing area as Lilenthal's but only half the weight. When testing this glider it was turned over by a cross wind and wrecked. Fortunately, Hargrave was not injured. This was the beginning and the end of his gliding experiments. He saw that safety was of paramount importance and that such an accident could cost him his life and put an end to his work. Both Lilenthal and Pilcher were to lose their lives in gliding accidents before the end of the century.

Hargrave's first full scale powered aeroplane was designed in 1895. This was to be doubly supported, firstly by a string of kites, and secondly, on its own wing surfaces when it got under way. This aircraft was not built, as the engine was a failure.

On the 20th April, 1896, the second full size power operated machine was designed. It was also to use box kite wings powered by a steam engine driving flappers. This machine was of particular interest as it incorporated a dual elevator rudder control and was to operate off water (a most original concept), supported by light wood or papier maché floats. The all-up weight was to be only 300 lb. Three engines, two steam and one petrol, built to power this machine were all failures.

His third full size powered machine was also to be a float plane. The proposed wing design was still on the box kite principle, but of curved section, showing evidence of his experimental work on soaring machines. The wings were further modified and improved in the final design for this machine developed in 1903. The arrangement of the floats was also improved and these were built, together with engine and wing supports. All the structure was made by Hargrave of tin sheet patiently soldered. A section of the main float was designed to carry water for the steam boiler. The design of this machine was in advance of the first generation aeroplanes built in Europe and U.S.A.

Hargrave calculated that 40 lb. of thrust was needed to drive this machine. The best he could obtain after several years of effort was only 17 lb.

In a letter to Octave Chanute on the 6th March, 1902, he said of this machine: "My new apparatus is merely a steamer if it does not lift out of the water and a flying machine if it does."

The Wright Bros.' aircraft made its first powered flight at the end of 1903. We cannot

be certain that Hargrave's first and second machines of 1895 and 1896 would have flown had Hargrave been able to develop a suitable engine. There can be little doubt, however, that his 1903 machine would have been a success. It was indeed a tragedy that Hargrave could not afford to outlay the funds necessary to build the wings and control surfaces until he was sure of the engine.

Hargrave carried out important experimental work on curved surfaces. This work began in 1892. At the beginning of 1893, he discovered that the curved sails of a windmill when turned so that the blade was edge-on to the wind, rotation was maintained and the whole sail assembly also moved forward on its axle. The full significance of this discovery was not realized until 1897 and valuable time was lost.

He then began a full series of experiments from which he deduced that wind striking a curved wing produced a reversal of air flow under the leading edge providing an aspirational effect on the wing. He designed simple wings balanced by a weight, which he called soaring machines. He found that these machines, when tethered, would advance beyond the zenith or perpendicular. It would appear that no further work has been done on this by others. If Hargrave's findings were correct, an important power source used by the soaring birds has been overlooked by later generations. This effect would be of vital importance in man-powered flight.

Aeronautical Work—Engines

Between 1896 and 1906, Lawrence Hargrave constructed five engines to power full size flying machines, and every one was a failure. It is interesting to speculate on the course of history should any one of these engines have been a success. Additionally, he constructed and exhaustively tested countless component parts, such as boilers, heat lamps, pumps, valves and propellers. It is almost unbelievably sad that such tremendous labour, originality and skill did not receive their due reward.

The two engines fitted with propellers, on display, are worth your inspection. The four cylinder motor in the test rig is petrol engine No. 24, built for the 1896 machine. The other is perhaps the most interesting. It was also built for the 1896 machine and its noteworthy features are light weight, compactness and the rotary movement. The tubular frame was designed to act as a container for water for the boiler and kerosene for firing. This engine was designed to produce five to six horsepower and must be one of the most unique steam engines ever built.

An extract from a letter to the Superintendent of the Railway Workshops, Sydney, written in March, 1900, indicates some of Hargrave's difficulties: "I am making a four cylinder oil (petrol) engine for my flying machine and on receiving the work that I had had done in a Sydney shop, I find the workmanship and material of sausage machine quality and on enquiry have not as yet found anyone who is likely to give me any more satisfaction."

On 29th October, 1900, he wrote: "Do you not see the crux of the whole matter is the engine. The motor car men are now helping by giving attention to light oil engines. I am driving at the same thing and although constantly failing, still see the certainty of success."

Two months later he wrote: "I have just had a bad knock in discovering some radical defects in my first attempt at a 4 cylinder oil engine, No. 24. This means 12 months work to do over again."

Hargrave was not to be beaten by his failures, for even when he was reluctantly obliged to give up full-time work on aviation in 1906, he designed and constructed yet another engine for his 1903 machine. A two-stroke petrol motor of two cylinders with recoil springs designed to operate flappers. This, too, was a failure.

Personal

Some very interesting material has recently been discovered, some of which I propose to quote in order to provide an insight into the range of Hargrave's interests and perhaps his character.

To his daughter in 1907: "I have been stuck over the drawing board for about two months and my twin two-stroke flapping flying machine motor looks as if it would work; Mum has lost all faith in me as an engineer owing to my long list of failures; she does not realise that a little success is only reached by climbing over piles of duffing jobs."

About the same time, and in reply to a letter which commented upon his brevity: "I understand your remarks about my short sentences, I find, the people who care to know do not misconstrue, those who want to carp have more scope if the writer is wordy."

One of his many letters to a newspaper: "Your leader in Saturday's issue traverses much ground but however good the idea of a universal language is, it is foredoomed from the jump because it is at variance with the fundamental truth that all living organisms are prone to vary. It is this law that always wrecks well-meaning socialistic efforts and makes an

ideal universal religion a hopeless impossibility. But onward rolls the river of life, cutting away the bank on one shore and making a sand bar elsewhere, ever changing, ever forgetting, let us hope ever improving."

An advertisement contemplated for publication in *Aeronautics*, London, 1910: "Lawrence Hargrave—After almost 25 years of continuous effort in assisting to make flying practical: finds that his present income is inadequate to meet the calls made upon it. He is 60 years of age, and still has considerable technical constructive ability, his is weak on theory. He wants to know if his services are of value to any one and, if so, what is their value—Continental papers please copy."

A letter to his daughter, 1914: "I never seem to have any news to tell you, it is very curious that when I take up my pencil to write on your letter, and all around are deep in various books, there seems to be instantly a buzz of talk, and jangle on the piano, of course the disturbance is only accidental and my noticing it is a sign of old age creeping on me."

A letter to the Secretary of the Royal Aeronautical Society, London, is probably an unequalled summing up of British character: "I note with pleasure all English aeronautical news that dribbles to me. It is typical of the English character throughout. Ridicule and intolerance of independent thought. Slowness to grasp the impact of a new idea. Opposition if a vested interest is assailed, curiosity if things are done in a far country. Tardy appreciation of danger when a neighbour threatens. A rapid and thorough seizure of that situation and then supremacy—may it be so."

Hargrave's contribution to the Royal Society's Symposium on the feeding of man—"What Man should eat": "The nutriment that a reasoning man should eat and drink in order that death should not be hastened by excess, can be regulated to any degree of accuracy. But our diet is rarely determined by reason, except in hospital or prison. We eat a pretty woman's cake and she smiles, we refuse and are dubbed bores, we drink a man's hard liquor and pretend we like it and henceforth rank as jolly good fellows, we reject his hospitality and lose a possible life-long friend. Strong indeed is he who adjusts his eating and drinking solely to work long and well—the intelligent man's eating and drinking are merely factors in the battle of life. The higher the intellect the greater the number of factors that enter the equation of the most trivial act."

A letter in 1915: "I wonder if the winners in this war will be any happier than the losers,

one must exterminate the other or spend all their time in making or using arms. The other must do the work of providing the necessities of life or be shot down. Treaties are no use and if made no one can be trusted to keep them if there is any advantage in breaking them. I hope we shall know how it turns out, but the world is old enough to have seen all this before and left no traces in our geological strata."

Team Work and Patents

Throughout his life, Hargrave was a champion of free enterprise, especially free trade, and wrote many letters to the newspapers on these subjects. As would be expected, he fought against monopoly in every form. However, he obtained reports on four occasions on the possibility of patenting various inventions. This action was probably taken against his better judgment and as the only way open to him of supplementing his slender income in order to provide the funds needed to more adequately carry out his experiments.

In a letter to the Secretary of the Smithsonian Society of 8th December, 1891, Hargrave said: "Will you impress upon your co-workers the fallacy of secrecy—co-operation and the full interchange of ideas will hasten success in which all will share—there are so many forms of flying machine possible that it is hopeless to think any inventor will be able to monopolise the profits by a corner."

An extract of a letter in 1888: "But bear in mind I am not working with any idea of making money by my results, I simply have leisure, inclination and constructive ability and use them in a field where I am sure of success."

In a paper to your Society read in June, 1890, he said: "The writer thinks the act of invention to be a sort of inspiration and a pleasure that the individual does not seek to be rewarded for undergoing—it is followed by a greedy sensation or a wish to obtain money from others without giving an equivalent. Inventors will always invent—they cannot help it—you cannot stop them and a patentee is nothing but a legal robber."

Inconsistencies

There are several major inconsistencies in Hargrave's work which are difficult to understand, particularly in such a period when the tempo of life provided adequate time for reflection. The chief of these was his failure to capitalize on his discovery of the lifting power of the curved surface in 1892. In 1893 he found that a box kite with curved surface planes

pulled twice as hard as one with flat surface planes. However, he came to the rather extraordinary conclusion that "a machine with curved surfaces would come to grief when flying against the wind if the wind fell calm unless surface area or driving power was increased, therefore he was on surer ground by making supporting surfaces as flat as possible". About this time, too, Chanute advised Hargrave that Lilenthal experiments with curved surfaces showed added lift of from three to seven times that of flat wings.

Five vital years passed before he again took up experimentation with curved surfaces, but even then they were not incorporated in the design of a full size machine until 1902.

In 1890 he announced in a paper to the Royal Society he had discovered that more than 50% of the supporting surface of his model aircraft was not necessary and that two separate areas were equally satisfactory. Although he built several models after this, none incorporated this discovery, which meant, of course, reduced drag and increased range.

Notwithstanding advice from a consulting engineer, whom he paid to report on the possibility of patenting his Trochoidal Plane propulsion methods in 1882, Hargrave persisted in his endeavours to apply this theory to aircraft. Even his last engine, built after he had virtually given up aviation work, was designed to drive flappers. A portion of the consulting engineer's report referred to reads as follows: "Propelling principles adopted by animate nature need not necessarily be the best for artificial propulsion and the probabilities are the other way." Yet Hargrave persisted to the end.

Again, Octave Chanute advised that propeller efficiency could be expected to be between 50% to 70%. Hargrave's propellers were generally under 20% efficiency. It is interesting to record, some thirty years later, the maximum efficiency obtained from fixed propellers was only 85%.

Misconceptions

Many people have not been able to understand why Hargrave gave 77 of his models to the Munich Museum in 1910. This caused much bitterness during the war years. The facts of the matter are that for eight years Hargrave endeavoured to interest the Sydney Technological Museum and the University in Sydney in them for permanent exhibition without suggestion of payment, even though some additional funds at that time were sorely needed.

They were also offered to the Melbourne Museum, Commonwealth Government, Royal Aeronautical Society in England, Science

Museum, Liverpool Museum, Smithsonian Institute and others. The famous Technological Museum at Munich did not hear of this offer until 1910. Their immediate application by cable was accepted, after which, of course, both the Commonwealth Government and the Sydney Technological Museum became interested, but it was too late.

The Munich Museum have now very generously returned all but four of the models, and several of them are on display tonight. Unfortunately, the major part of the collection was destroyed in the last war. This is perhaps a true measure of Hargrave's considered worth in this country when he could not even give away results of his work. Yet here was a man who, but for an unfortunate chain of adversity, would have been one of the truly great in history.

Since Hargrave's death, many references have been made, particularly in the press, to the Wrights' indebtedness to Hargrave for their success. There is no foundation for these statements. Hargrave wrote only two letters to the Wrights. One was of congratulation after he had learned of their first flight. Both were short and to the point.

Investigations lead me to believe, however, that there is a strong, indirect link through Octave Chanute. Records suggest that the significance of Hargrave's early work on curved surfaces, which was not missed by Chanute, influenced the design of his famous gliders. There is little doubt that the design of the Wright glider was based initially on the Chanute glider, which preceded it by several years. It is an interesting speculation.

Vision

Not by any means the least of Hargrave's contributions to aviation was his well-developed sense of history expressed in many ways, but particularly in preserving his models for the guidance of experimenters and the information of the public, and in the meticulous record of his work contained in his notebooks and the papers given to your Society.

Notwithstanding an almost unbelievable record of failures, Hargrave never wavered either in the course he had set himself or his conviction that man would fly in a heavier than air machine and that the aeroplane was the chosen instrument for transportation in the future. "Let no man be disheartened by the sneers of know-all acquaintances. Rely on it that the first man who paddled across a creek astride a log was thought a hare-brained fool by his contemporaries."

Two letters written in 1902 are of interest :

"We should have been flying long since had it not been for the unfortunate invention of the balloon."

"I can fully appreciate the splendid work of those engaged in driving balloons, but they must see as clearly as I do that such machines, however successful they may be, cannot be a type that will have any permanence."

In a letter to the Smithsonian Institute dated 1891, he said: "Very few have the slightest idea of the results of our work, but there are some here who can actually speak about flying machines without that pitying smile that is so galling to the recipient." The reply is equally interesting: "I congratulate you on your success. Work done by experimenters like yourself is to be regarded as most valuable and the success you have achieved gives renewed hope to all in the final solution of a problem which, when solved, will produce an effect upon civilisation greater than any since the invention of the steam engine."

A fitting conclusion to this part dealing with the vision of Hargrave is to be found in a letter to Chanute in 1892: "There is an opinion that the principal work of the flying machine will be to destroy life—this idea may predominate amongst men in the trade (referring to Maxium who was then building a huge machine at a cost of £20,000) but it is erroneous. The flying machine will tend to bring peace and goodwill to all, it will throw light on the few unexplored corners of the earth and will herald the downfall of all restrictions to the free intercourse of nations."

His Place in Aeronautical History

Some thought was given to the title of this paper, and it was considered that "An Appreciation" was adequate, although in modern usage the word "appreciation" tends to be regarded as "speaking in favour of". The dictionary, however, gives the meaning intended of "a just estimate". History has not been just to Lawrence Hargrave. The aim of tonight's paper has been to attempt to redress the balance.

You will have noted that many quotations have been given from his records. This has been done partly to permit you to form your own opinion, but mainly because a number of the references have been taken from papers he gave to your Society 70 to 80 years ago.

Before concluding, I would like to attempt to draw together some of the threads of this broad canvas.

An important feature of Hargrave's work was his planned and logical approach. Firstly,

he set out to prove his assumption that human flight in a heavier than air machine was possible. He decided that proof could best be demonstrated by the use of models. Concurrently with this work, he began experimenting with power plant design as he realized it was in this direction that the main difficulties lay.

He resisted the temptation to develop and improve his model aircraft and turned instead to the next step, stability and safety aloft. Hargrave realized that an accident could put an end to his work, so he made safety a major requirement. It was also clear to him that the first navigator of the skies in a heavier than air machine would have his hands very full indeed. He set out to minimize the problems with which he would have to contend and considered the achievement of stability was of paramount importance. His box kites were the brilliant realization of that aim.

Today, the box kite sounds a very simple affair—a child's toy. Hargrave had developed his box kites to become quite sophisticated flying machines. His three-deck box kite, for instance, had a surface area of 158 sq. ft., with 11 ft. 6 in. span, 10 ft. long and 2 ft. 6 in. high. There can be little doubt that Hargrave would have flown had he been able to obtain a satisfactory motor. We have the first generation of European aviators to bear witness, as their wing design was purely the box kite invented by Hargrave some 15 years earlier.

There is one essential difference, however. The Europeans did not have Hargrave's knowledge of the subject. They snatched Hargrave's wing design in almost desperation and instead of developing and improving the wing as Hargrave would have done, persisted with it in its original form and for several years could not turn corners until the Wrights showed them how in 1909.

It is certain that once Hargrave had achieved flight and had learnt to control his machine, he would have progressively modified the stability factors he had designed for safety. In a paper to the Royal Society as far back as 1885, it was clear he could see the road ahead. Speaking of control, he said: "In larger machines this will have to be done by making the area of the tail variable for ascending or descending and tilting one corner up and down for turning to either side." He had anticipated aileron control which the Wrights reinvented 20 years later.

Perhaps the most significant of Hargrave's many contributions to man's final conquest of the air was his taking up the torch of experi-

mentation when it had been dropped by the Europeans in the 80's and keeping it burning brightly for 25 vital years. His approach was a scientific one and it was made quite unique by his sharing of the results of his work and thinking with anyone who expressed a genuine interest. His dogged perseverance and unflinching optimism were an inspiration to many. Strangely enough, these virtues were to some extent a handicap, as they caused him to persist in unrewarding endeavour when his energies may have brought better results in other directions.

He was a superb draftsman, and his engines were all built firstly on the drawing board, often after weeks of work. Many of these drawings are in the library of the Royal Aeronautical Society, London. His skill as a draftsman was almost equalled by his skill as an engineer, as you may see by examination of the equipment in the hall, which has been very generously lent by the Trustees of the Museum of Arts and Sciences.

The originality of Hargrave's designs is quite remarkable, but originality was not enough when it came to engines and associated equipment. This problem could have been overcome had Hargrave had a larger income, been assisted financially in his work, or had had a fellow worker to help him, as Orville Wright had in Wilbur. His income was fixed at approximately £600 per annum. The combined effects of inflation and family growth meant that his surplus funds dwindled to extinction when they were needed most for full-scale work. In 1902, when he was so near to success, he sent a desperate appeal for funds to the *London Times*—without result.

This is a sad story with a tragic end, but it demonstrates, once again, the slender margin between success and failure. Hargrave had the attributes of character, skill, enterprise and hard work which deserved a better result. However, had he flown, it is certain he would not have claimed the success for himself. Due credit would have been generously given to the contributions made by many others, without whose work of dedicated endeavour, spread over 100 years, the brilliant achievement of the Wright brothers would not have been possible in December, 1903.

In conclusion, one final quotation from the American Octave Chanute, who was unquestionably the greatest aviation authority of this period. He said in a public gathering in 1894: "If there is a man more than another who deserves to fly through the air, that man is Lawrence Hargrave of Sydney, N.S.W."

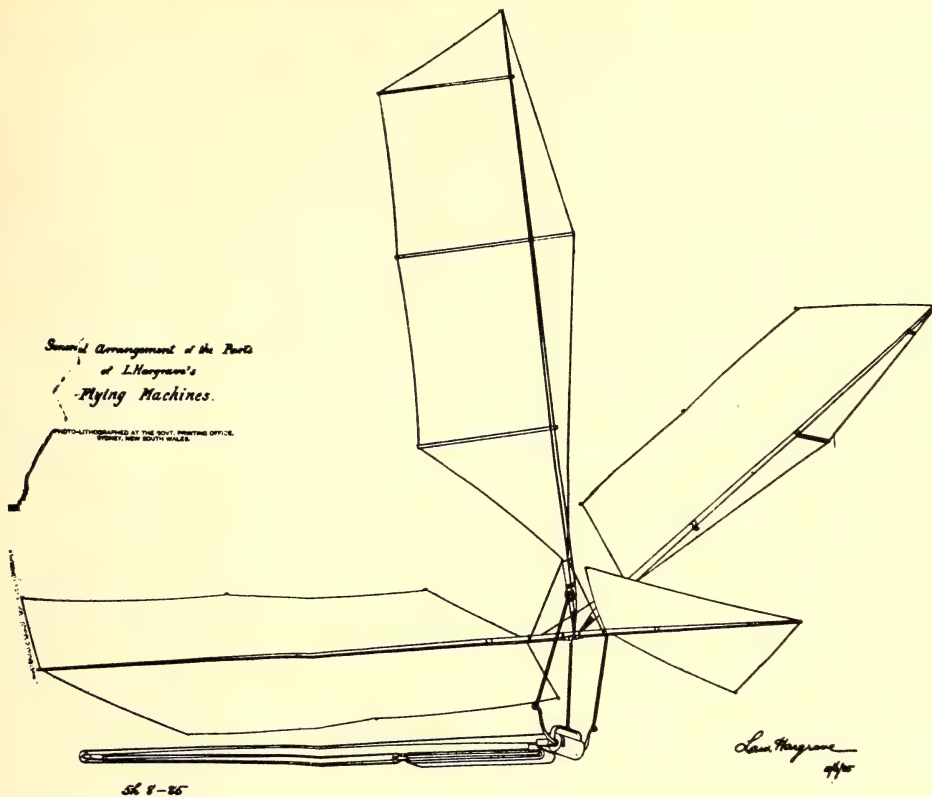


FIG. 1

Hargrave's perspective drawing of india rubber powered flapper operated flying machine of 1885

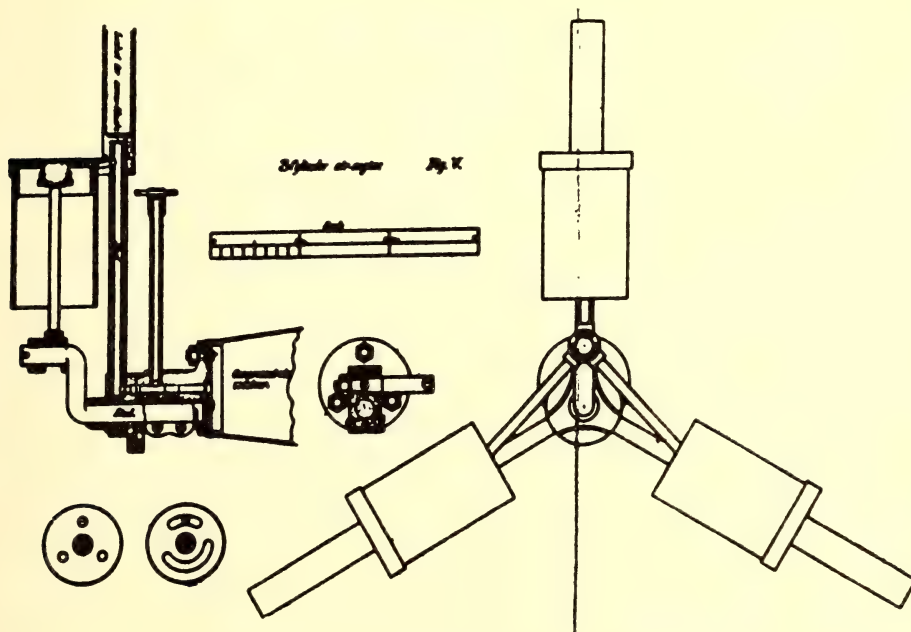


FIG. 2

Hargrave's drawing of the three cylinder radial rotary compressed air engine invented 1889

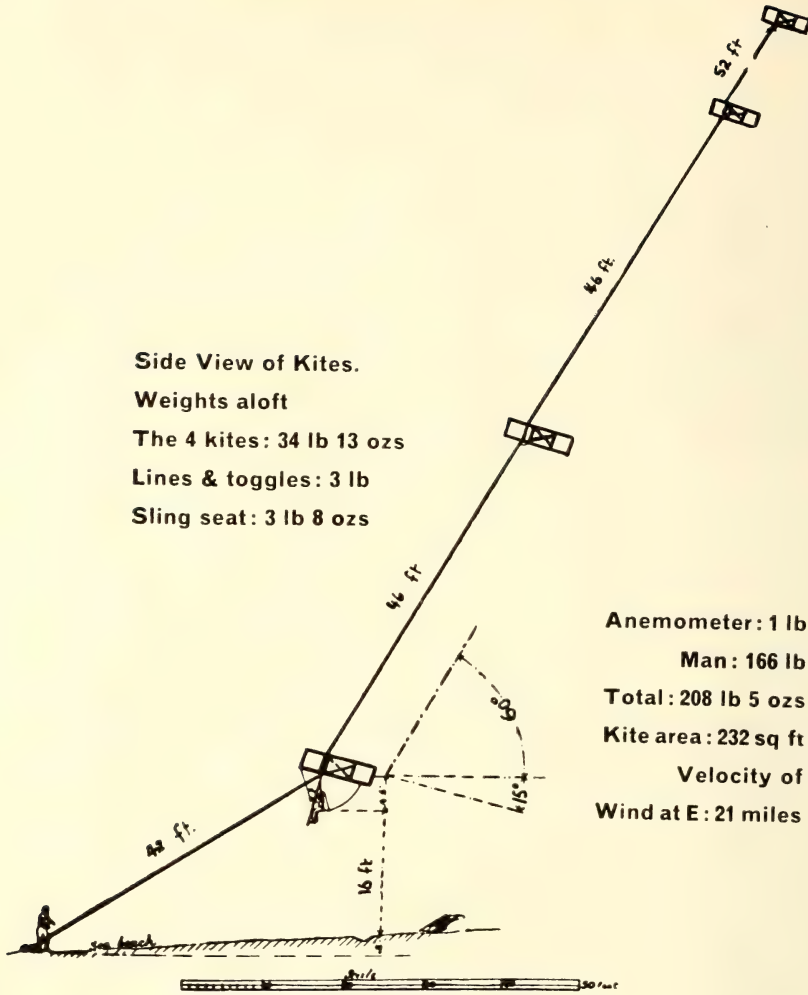


FIG. 3
Drawing of the man lift by four box kites 1894

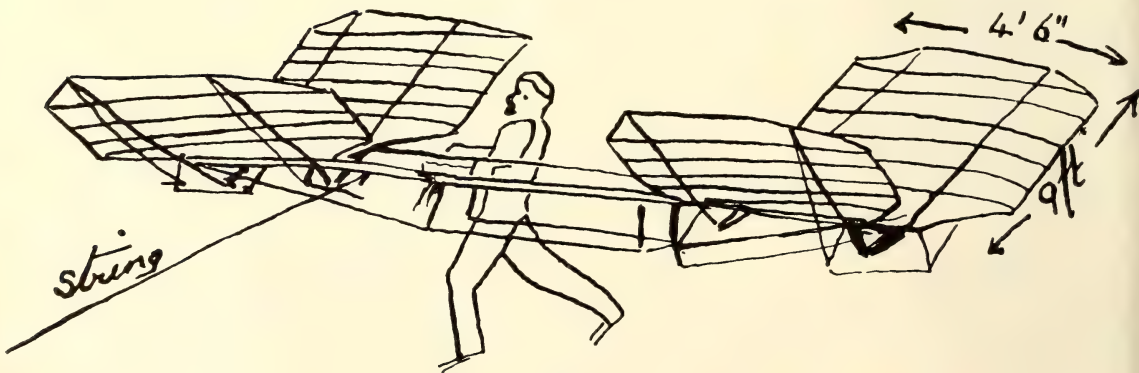


FIG. 4
Hargrave's sketch of the monoplane glider built 1894

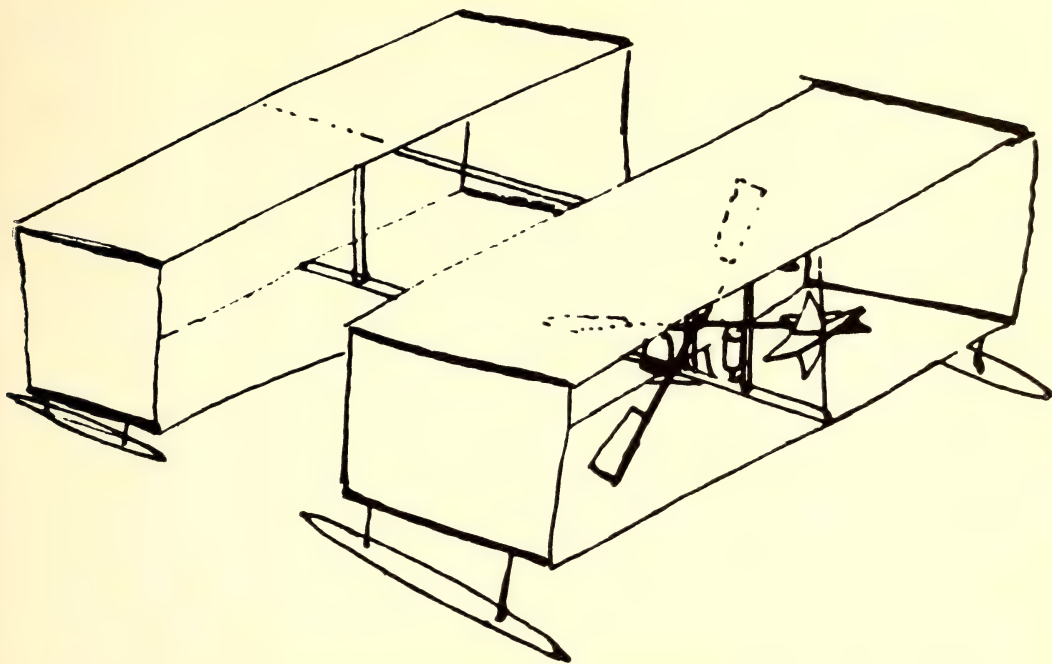


FIG. 5

Hargrave's sketch of his second design (1896) for a full-size power operated aeroplane for operation off the water. The machine was not built, as four engines designed to power it were all failures

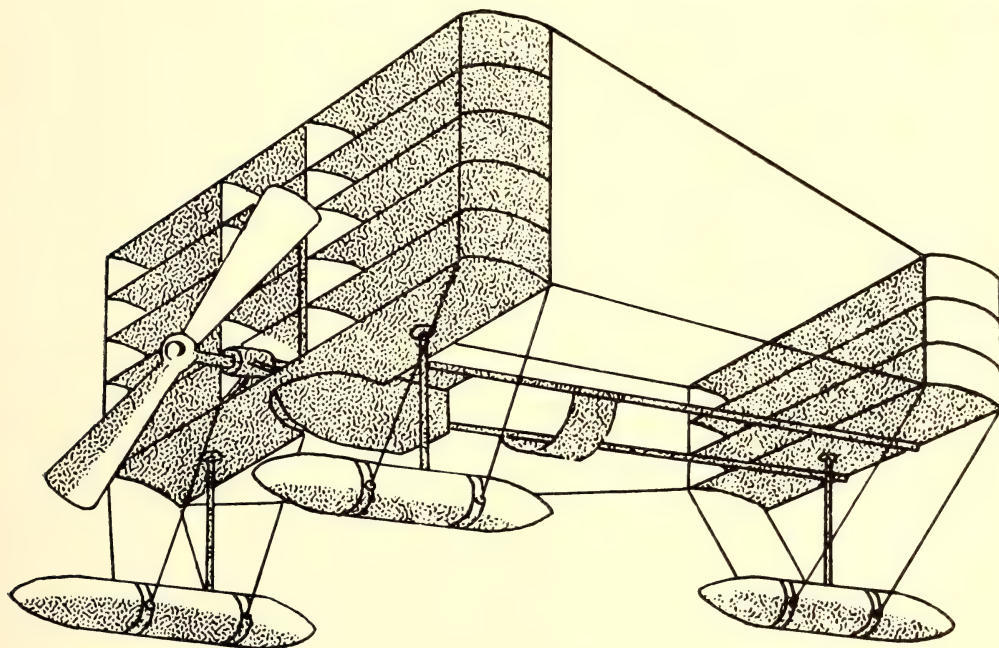


FIG. 6

Hargrave's drawing of his third design for a full-size powered aeroplane of 1902. The steam engine built to drive it was a failure. Note the sophisticated design and arrangement of the supporting surface which many years later was adopted by most aeroplane manufacturers. The floats were built in a much improved form in the 1903 machine



FIG. 7

Actual photograph of the modified design of the floats of the 1902 aeroplane. Main float 25' 7" long, weight 25 lb. also served as a container for water and fuel for the steam boiler. Designed all-up weight of this aeroplane, 471 lb. with a wing loading of 1 lb. per sq. ft. Photograph taken in 1905 at the rear of the Hargrave home on Woollahra Point. Note alternative propellor in foreground

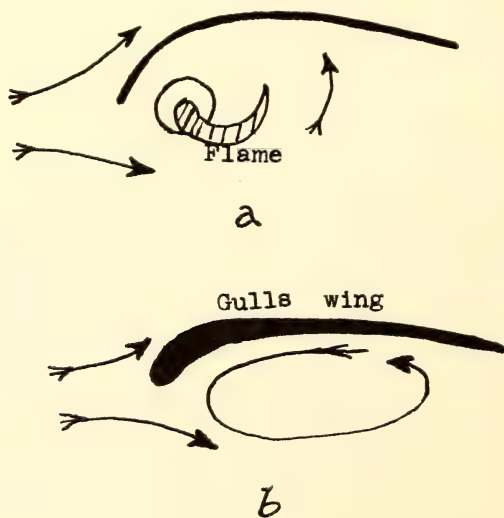
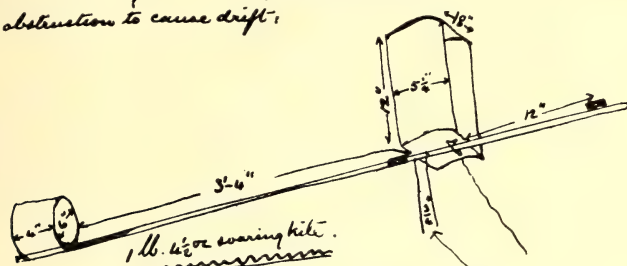


FIG. 8

Section of wing forms showing Hargrave's discovery of reverse air flow under the leading edge demonstrated by the movement of a candle flame and smoke. (Redrawn)

102 Sept. 27^E 1897. Wind N.E. steady, about 14 miles. No soaring done with vertical tail and pendant weight: the cylindrical aluminium tail is simplest to make, shows the least obstruction to cause drift:



This kite made the complete circuit at the full stretch of the string, twice.

It soared over the line many more times (say 10)



Section No. 23. cylinders & pistons of rotary engine were put in place & the engine turned round for the first time: it looks as if it was going to work well.

Sept. 27 1897. It seems to me that this wing tips of a soaring bird act in a manner to produce automatic stability: they are too flat to have any vortex-producing function. I could combine the plane & soaring curve in several ways A.B.C. I think C the best for

FIG. 9

Portion of a page of a Hargrave notebook of 1897 showing one of the early types of soaring machines

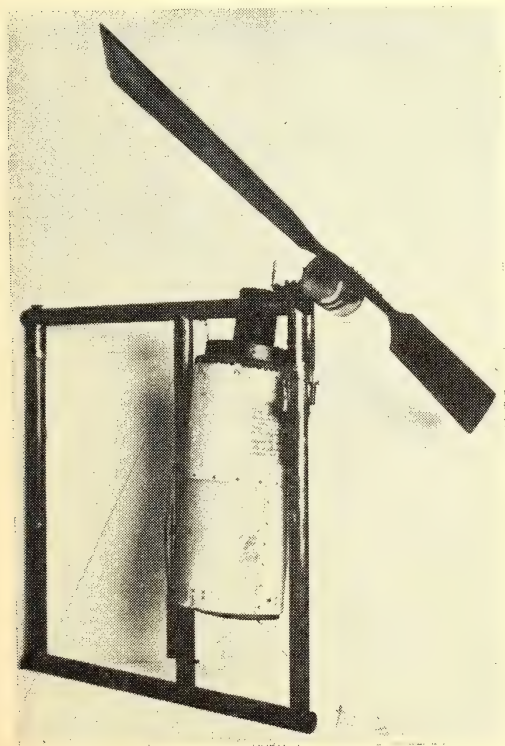


FIG. 10

No. 23 steam operated twin cylinder rotary engine built to power the 1896 aeroplane, showing steam boiler and tubular frame which also served as a container for water and kerosene for the operation of the boiler. Engine built in 1898

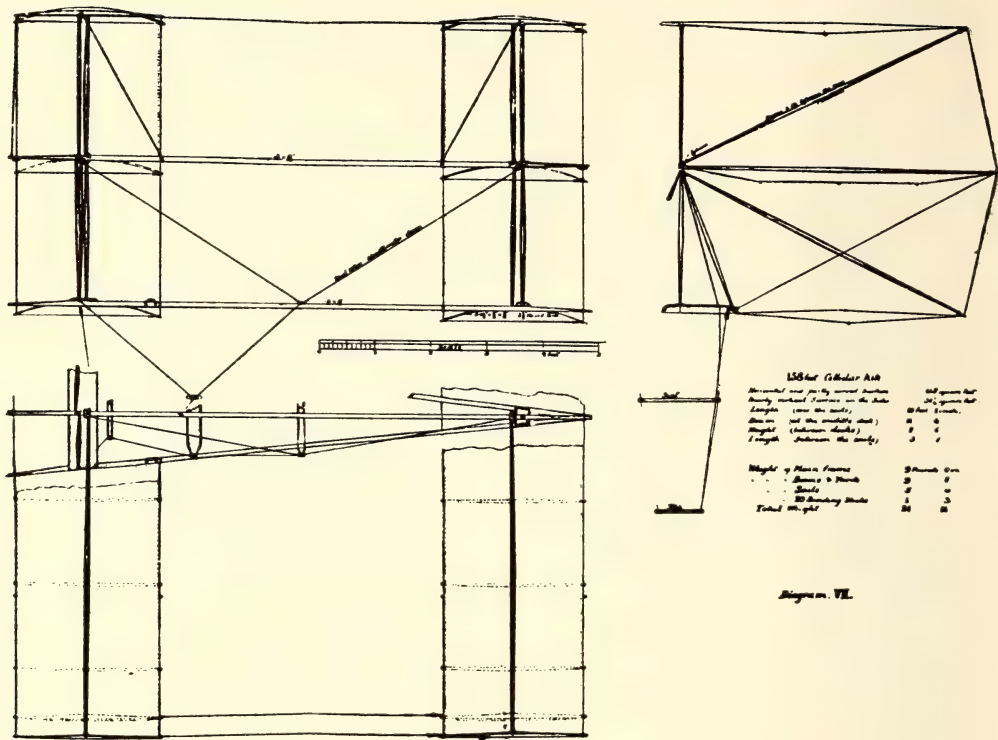


FIG. 11

Hargrave's drawing of his 158 sq. ft. triplane box kite of only 25 lb. weight of 1895, showing the development in the design of supporting surfaces culminating in the 1902 aeroplane

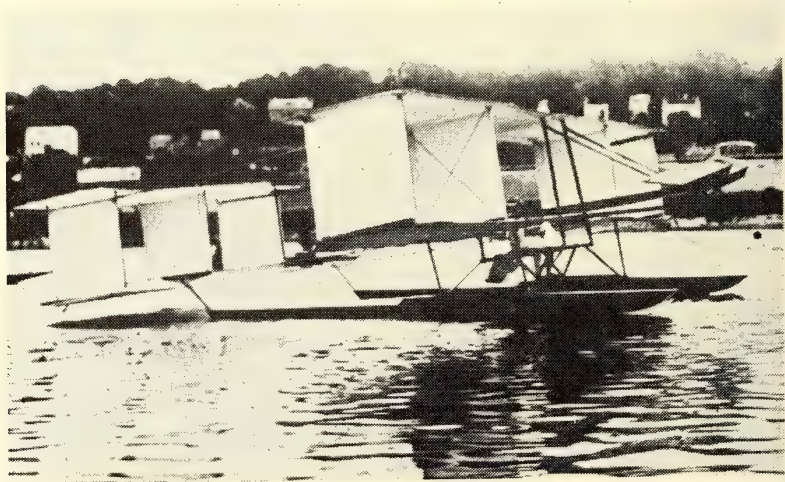


FIG. 12

The first aircraft to use the Hargrave box kite wing design was the Voisin-Archdeacon float glider built in Paris. It flew successfully when towed by a launch on the River Seine

Minor Planets Observed at Sydney Observatory During 1961

W. H. ROBERTSON
Sydney Observatory, Sydney

The following observations of minor planets were made photographically at Sydney Observatory with the 9-inch Taylor, Taylor and Hobson lens. Observations were confined to those with southern declinations in the *Ephemerides of Minor Planets* published by the Institute of Theoretical Astronomy at Leningrad.

On each plate two exposures, separated in declination by approximately 0'.5, were taken with an interval of about 20 minutes between them. The beginnings and endings of the exposures were automatically recorded on a chronograph by a contact on the shutter.

Rectangular coordinates of both images of the minor planet and three reference stars were measured in direct and reversed positions of the plate on a long screw measuring machine. The usual three star dependence reduction retaining second order terms in the differences of the equatorial coordinates was used. Proper motions, when they were available, were applied to bring the star positions to the epoch of the

plate. Each exposure was reduced separately in order to provide a check by comparing the difference between the two positions with the motion derived from the ephemeris. The tabulated results are means of the two positions at the average time except in cases 1155, 1172, 1206, 1211, 1227, 1281 where each result is from only one image, due to a defect in the other exposure or a failure in timing it. No correction has been applied for aberration, light time or parallax but in Table I are given the factors which give the parallax correction when divided by the distance. The serial numbers follow on from those of a previous paper (Robertson, 1962). The observers named in Table II are W. H. Robertson (R), K. P. Sims (S) and H. W. Wood (W). The measurements were made by Miss J. Hawkes and Mrs. Y. Lake, who have also assisted in the computation.

Reference

ROBERTSON, W. H., 1962. *J. Proc. Roy. Soc. N.S.W.*, 95, 153. *Sydney Observatory Papers*, 41.

TABLE I

No.	Planet	U.T.		R.A. (1950.0)			Dec. (1950.0)			Parallax Factors	
				h	m	s	°	'	"	s	"
1150	32	1961 Jun	19.63670	18	42	08.57	-15	39	07.8	+0.06	-2.7
1151	32	1961 Jun	27.63759	18	34	42.26	-15	32	37.2	+0.15	-2.8
1152	45	1961 Aug	22.61778	22	53	26.74	-08	50	57.7	+0.01	-3.7
1153	45	1961 Sep	26.52860	22	28	18.93	-12	35	34.3	+0.08	-3.2
1154	71	1961 Jun	19.57181	17	40	48.17	-53	57	25.2	-0.01	+3.0
1155	71	1961 Jul	03.54252	17	23	00.72	-51	25	23.3	+0.09	+2.6
1156	76	1961 Jul	03.66137	20	23	49.09	-16	34	31.9	+0.04	-2.6
1157	76	1961 Jul	04.64013	20	23	13.68	-16	36	14.9	-0.02	-2.6
1158	91	1961 Aug	01.56832	19	38	21.65	-24	40	55.2	+0.10	-1.4
1159	91	1961 Aug	08.51203	19	32	30.05	-24	49	10.7	-0.01	-1.4
1160	94	1961 Jun	20.55722	17	01	44.22	-33	53	01.4	+0.05	0.0
1161	94	1961 Jul	03.51278	16	51	23.33	-33	28	13.0	+0.04	0.0
1162	98	1961 May	15.60062	16	16	03.12	-44	50	23.2	-0.05	+1.7
1163	98	1961 Jun	07.57193	15	47	56.88	-44	21	58.0	+0.18	+1.4
1164	98	1961 Jun	15.53351	15	40	03.42	-43	43	54.9	+0.14	+1.6
1165	100	1961 Sep	21.61898	00	56	52.08	-03	11	52.8	0.00	-4.5
1166	103	1961 Jul	24.64348	22	04	15.17	-12	08	57.2	-0.03	-3.2
1167	104	1961 May	08.62012	15	16	26.34	-18	42	19.1	+0.10	-2.3
1168	124	1961 Jun	26.53613	17	10	39.26	-18	06	49.1	+0.01	-2.4
1169	124	1961 Jul	04.50276	17	04	45.52	-18	03	45.9	-0.02	-2.4
1170	144	1961 May	04.55021	14	20	23.88	-09	23	27.4	-0.03	-3.6
1171	144	1961 May	16.55048	14	10	21.02	-08	47	23.0	+0.09	-3.7

TABLE I—*continued*

No.	Planet	U.T.	R.A. (1950·0)	Dec. (1950·0)	Parallax Factors	
			h m s	° ' "	s	"
1172	146	1961 Sep	21·57406	23 41 26·24	-23 51 41·7	+0·02 -1·5
1173	150	1961 May	08·58358	14 38 16·20	-14 28 58·7	+0·07 -2·9
1174	150	1961 May	23·52438	14 27 15·11	-13 29 25·3	+0·03 -3·0
1175	151	1961 May	08·62012	15 14 55·81	-20 13 29·8	+0·10 -2·1
1176	159	1961 Jul	10·63341	20 00 58·51	-17 40 28·0	+0·06 -2·5
1177	161	1961 Jul	24·61601	20 56 55·09	-35 02 51·6	+0·01 +0·2
1178	161	1961 Aug	21·52607	20 28 34·13	-34 43 14·3	+0·03 +0·1
1179	162	1961 Jul	03·62722	19 41 59·72	-29 40 02·6	+0·03 -0·6
1180	162	1961 Jul	19·59742	19 27 50·71	-30 16 36·7	+0·11 -0·6
1181	178	1961 Jul	04·60874	19 32 44·57	-24 32 27·8	-0·01 -1·4
1182	178	1961 Aug	01·53308	19 06 17·29	-25 28 54·7	+0·06 -1·3
1183	188	1961 Jun	26·66926	20 05 06·14	-04 53 19·6	+0·05 -4·2
1184	191	1961 Jul	04·56743	18 31 20·75	-08 03 03·3	0·00 -3·8
1185	191	1961 Jul	11·54024	18 25 41·88	-08 24 51·1	-0·01 -3·8
1186	193	1961 Aug	22·61778	22 56 12·05	-12 14 11·3	0·00 -3·2
1187	193	1961 Sep	26·52860	22 19 35·68	-12 17 58·3	+0·10 -3·2
1188	208	1961 May	08·66671	16 36 26·60	-24 18 53·4	+0·08 -1·5
1189	208	1961 Jun	07·60959	16 10 46·85	-23 32 18·0	+0·21 -1·8
1190	222	1961 Jun	07·68808	18 25 41·19	-23 49 13·3	+0·17 -1·7
1191	222	1961 Jul	04·53230	18 03 43·30	-24 20 07·0	-0·06 -1·4
1192	233	1961 May	04·52606	13 41 31·08	-12 25 37·1	-0·02 -3·2
1193	233	1961 May	23·49241	13 30 15·75	-10 27 48·9	+0·06 -3·5
1194	240	1961 May	09·58278	15 06 35·90	-14 34 36·4	+0·01 -2·9
1195	250	1961 May	04·52606	13 49 38·09	-14 34 55·7	-0·04 -2·9
1196	250	1961 May	09·54524	13 45 44·75	-14 27 21·3	+0·07 -2·9
1197	254	1961 May	22·63788	17 07 52·82	-29 02 01·4	+0·03 -0·7
1198	254	1961 Jun	14·55378	16 43 24·63	-29 36 26·4	+0·02 -0·6
1199	278	1961 May	08·58358	14 38 54·33	-10 58 30·4	+0·07 -3·4
1200	278	1961 May	23·52438	14 26 29·45	-11 03 34·7	+0·04 -3·4
1201	298	1961 Jul	19·63810	20 36 13·92	-28 44 34·3	+0·09 -0·8
1202	306	1961 Sep	26·55998	23 54 04·92	-09 41 29·3	-0·01 -3·6
1203	331	1961 May	17·67908	17 29 21·76	-30 11 20·5	+0·08 -0·6
1204	331	1961 May	22·63788	17 25 47·90	-30 19 53·1	+0·01 -0·5
1205	334	1961 Aug	01·64487	21 50 14·31	-14 13 27·7	+0·05 -3·0
1206	338	1961 Aug	22·55729	21 02 12·97	-11 51 39·2	+0·06 -3·3
1207	342	1961 Jul	05·63653	19 45 31·10	-11 32 11·3	+0·06 -3·3
1208	342	1961 Aug	08·47406	19 16 10·60	-12 21 12·4	-0·09 -3·2
1209	346	1961 Jun	26·60525	18 55 19·61	-24 38 14·7	0·00 -1·4
1210	366	1961 Jun	20·63647	18 50 43·54	-38 03 37·8	+0·06 +0·6
1211	366	1961 Jul	10·57209	18 31 20·08	-37 57 59·8	+0·08 +0·6
1212	374	1961 Apr	11·55272	12 42 39·91	-10 40 23·4	-0·01 -3·4
1213	374	1961 May	02·50120	12 30 10·05	-07 50 19·0	+0·04 -3·8
1214	382	1961 May	02·55955	13 52 57·71	-24 18 15·0	+0·04 -1·4
1215	382	1961 May	08·54724	13 48 25·11	-23 50 59·3	+0·07 -1·5
1216	382	1961 May	16·51219	13 43 14·67	-23 11 55·2	+0·03 -1·6
1217	384	1961 Aug	21·66230	23 23 44·24	-12 49 47·4	+0·07 -3·2
1218	384	1961 Sep	20·55092	22 58 13·59	-15 03 50·7	+0·04 -2·8
1219	392	1961 May	23·59474	15 52 13·51	-09 34 37·3	+0·07 -3·6
1220	392	1961 Jun	19·52752	15 33 28·45	-07 41 48·0	+0·13 -3·9
1221	410	1961 Sep	21·59134	00 16 12·21	-17 29 00·3	0·00 -2·5
1222	410	1961 Oct	19·50890	23 54 47·23	-18 26 42·9	+0·03 -2·3
1223	413	1961 Oct	10·64369	02 30 50·79	-28 24 23·8	+0·04 -0·8
1224	413	1961 Oct	25·61487	02 18 02·12	-27 49 02·8	+0·11 -1·0
1225	442	1961 Jul	03·66137	20 16 39·37	-15 47 04·4	+0·06 -2·7
1226	442	1961 Jul	11·61843	20 09 52·94	-16 29 06·7	0·00 -2·6
1227	451	1961 May	04·64353	16 14 22·30	-09 22 28·2	+0·01 -3·6
1228	451	1961 May	23·59474	15 59 05·56	-09 24 04·9	+0·05 -3·6
1229	455	1961 Jul	05·59471	19 17 07·33	-33 10 09·0	+0·07 -0·1
1230	455	1961 Jul	26·54392	18 55 51·89	-36 00 15·0	+0·07 +0·3
1231	471	1961 Oct	19·55828	01 44 10·35	-14 24 46·0	-0·05 -2·9
1232	471	1961 Oct	31·51588	01 33 38·26	-13 58 04·0	-0·06 -3·0
1233	508	1961 Sep	20·58030	23 57 04·69	-16 49 16·6	0·00 -1·7
1234	508	1961 Oct	12·52360	23 40 15·27	-17 01 19·4	+0·05 -2·5

TABLE I—*continued*

No.	Planet	U.T.			R.A. (1950.0)			Dec. (1950.0)			Parallax Factors	
					h	m	s	°	'	"	s	"
1235	514	1961 Jul	03.66137	20	16	21.84	-17	11	19.9	+0.06	-2.5	
1236	514	1961 Jul	10.63341	20	11	13.01	-17	18	25.5	+0.04	-2.5	
1237	524	1961 Jun	14.64502	18	38	28.24	-33	26	06.1	+0.06	-0.1	
1238	524	1961 Jul	05.55298	18	16	24.04	-33	12	46.8	-0.01	-0.1	
1239	528	1961 May	08.62012	15	25	49.22	-19	12	15.4	+0.08	-2.2	
1240	528	1961 May	23.55815	15	13	30.77	-19	11	26.8	+0.04	-2.2	
1241	532	1961 Sep	20.61432	00	24	51.57	-21	17	41.7	+0.05	-1.9	
1242	532	1961 Oct	19.53378	00	02	55.57	-22	58	25.6	+0.09	-1.7	
1243	550	1961 May	08.54724	13	50	49.63	-25	15	41.3	+0.06	-1.3	
1244	550	1961 May	16.51219	13	44	27.25	-24	07	36.9	+0.03	-1.5	
1245	554	1961 May	04.66260	16	50	54.18	-25	59	26.1	-0.01	-1.2	
1246	554	1961 May	08.66671	16	47	50.81	-25	55	11.1	+0.05	-1.2	
1247	554	1961 Jun	07.60959	16	17	55.97	-24	42	54.4	+0.20	-1.6	
1248	567	1961 Jul	05.59471	19	17	26.72	-32	22	29.4	+0.07	-0.2	
1249	569	1961 Jul	12.67400	21	09	13.52	-16	14	35.1	+0.06	-2.7	
1250	573	1961 May	16.51219	13	53	34.59	-24	15	56.1	+0.01	-1.4	
1251	576	1961 May	09.62398	15	59	24.08	-34	34	31.2	+0.03	+0.1	
1252	576	1961 Jun	15.50332	15	26	53.06	-31	43	28.4	+0.04	-0.3	
1253	579	1961 Jun	07.68808	18	29	24.94	-25	12	56.7	+0.16	-1.4	
1254	579	1961 Jul	04.53230	18	05	53.02	-27	06	37.8	-0.06	-1.0	
1255	586	1961 Jul	12.63116	20	28	40.02	-16	48	44.1	+0.01	-2.6	
1256	586	1961 Jul	18.66715	20	24	02.75	-17	03	04.3	+0.19	-2.7	
1257	615	1961 Aug	22.61778	23	01	04.54	-09	12	44.4	-0.01	-3.7	
1258	634	1961 Aug	01.64487	21	46	18.62	-15	00	54.1	+0.06	-2.8	
1259	644	1961 Aug	01.64487	21	47	29.46	-14	14	38.6	+0.06	-2.9	
1260	674	1961 May	04.66260	16	46	07.58	-24	22	07.5	0.00	-1.4	
1261	674	1961 May	08.66671	16	43	09.76	-24	29	41.4	+0.06	-1.4	
1262	674	1961 Jun	07.60959	16	16	08.30	-25	02	25.4	+0.20	-1.6	
1263	679	1961 Jul	10.63341	20	01	44.38	-21	25	27.4	+0.06	-1.9	
1264	679	1961 Jul	24.57182	19	47	19.52	-25	17	50.7	+0.02	-1.3	
1265	702	1961 Jun	26.64228	19	24	29.94	-25	09	45.4	+0.05	-1.3	
1266	702	1961 Aug	01.50400	18	52	12.51	-22	37	04.1	-0.01	-1.7	
1267	735	1961 Jul	03.59471	19	09	34.98	-49	02	46.6	-0.01	-2.3	
1268	735	1961 Jul	12.59120	18	57	59.32	-50	10	24.4	+0.13	-2.4	
1269	737	1961 May	04.61175	15	46	24.21	-04	24	28.4	-0.03	-4.3	
1270	780	1961 Sep	18.61478	00	24	39.39	-15	09	47.4	+0.03	-2.8	
1271	785	1961 Oct	10.58482	01	13	38.55	-09	23	34.8	+0.02	-3.6	
1272	785	1961 Nov	09.47138	00	49	39.58	-09	48	48.9	-0.03	-3.6	
1273	786	1961 Oct	12.55870	00	06	17.34	-20	53	32.6	+0.10	-2.0	
1274	800	1961 May	17.67908	17	22	46.11	-31	26	59.4	+0.08	-0.4	
1275	800	1961 May	22.63788	17	19	18.98	-31	32	57.0	+0.01	-0.3	
1276	828	1961 Jul	12.67400	21	12	43.25	-17	34	52.7	+0.05	-2.5	
1277	834	1961 Aug	22.65590	23	31	38.34	-00	57	21.6	+0.04	-4.8	
1278	834	1961 Sep	27.52515	23	07	04.17	-04	25	03.8	-0.01	-4.3	
1279	844	1961 Aug	22.61778	22	53	27.28	-10	16	25.8	+0.01	-3.5	
1280	844	1961 Sep	26.52860	22	26	43.45	-11	01	56.9	+0.08	-3.4	
1281	860	1961 Jun	19.68834	20	19	34.06	-27	27	07.4	+0.02	-1.0	
1282	860	1961 Aug	01.56832	19	39	45.10	-25	38	58.3	+0.10	-1.3	
1283	888	1961 Sep	12.67986	00	43	54.45	-15	50	57.8	+0.14	-2.8	
1284	888	1961 Oct	10.55094	00	23	42.81	-19	50	32.9	+0.02	-2.1	
1285	892	1961 Oct	12.60832	02	02	19.65	-03	55	36.1	0.00	-4.4	
1286	901	1961 Jul	12.63116	20	26	02.84	-15	02	28.6	+0.02	-2.8	
1287	901	1961 Jul	18.66715	20	21	10.72	-14	54	53.7	+0.19	-3.0	
1288	914	1961 May	02.61434	15	31	42.36	-39	03	43.2	-0.01	+0.8	
1289	927	1961 May	08.54724	13	55	23.58	-23	35	02.1	+0.05	-1.6	
1290	927	1961 May	16.51219	13	49	09.26	-23	20	32.2	+0.02	-1.6	
1291	934	1961 Aug	01.60675	21	18	14.51	-21	26	32.4	0.00	-1.9	
1292	934	1961 Aug	21.55262	20	56	40.66	-20	45	15.0	+0.05	-2.0	
1293	934	1961 Sep	04.48884	20	44	29.68	-19	53	30.9	-0.01	-2.1	
1294	980	1961 Apr	11.68158	15	31	22.94	-38	36	27.8	+0.03	+0.8	
1295	980	1961 May	04.58307	15	12	35.60	-38	06	30.8	-0.05	+0.6	
1296	980	1961 May	15.55903	15	01	25.49	-37	10	50.2	0.00	+0.5	
1297	983	1961 Jun	20.59697	17	54	49.50	-16	18	11.7	+0.05	-2.6	

TABLE I—*continued*

No.	Planet	U.T.	R.A. (1950.0)			Dec. (1950.0)			Parallax Factors	
			h	m	s	°	'	"	s	"
1298	983	1961 Jul	05	51	53.4	17	42	47.22	-0.05	-2.8
1299	1015	1961 Aug	22	58	20.6	22	04	08.91	0.00	-2.3
1300	1042	1961 Aug	21	62	72.1	22	45	01.08	+0.05	+1.3
1301	1117	1961 Aug	21	58	54.8	22	03	41.77	0.00	-3.2
1302	1117	1961 Sep	13	51	05.0	21	49	00.50	0.00	-2.8
1303	1127	1961 Oct	30	59	82.4	03	08	45.55	-0.02	-3.1
1304	1127	1961 Dec	05	48	35.2	02	44	27.05	-0.02	-3.4
1305	1146	1961 May	16	65	50.2	16	16	24.18	+0.14	-3.8
1306	1146	1961 Jun	14	51	85.3	15	56	24.81	+0.01	-4.4
1307	1167	1961 Jun	19	63	67.0	18	46	25.90	+0.06	-2.6
1308	1186	1961 Sep	19	62	12.3	00	14	47.21	+0.08	-3.3
1309	1186	1961 Oct	11	54	19.9	23	56	36.36	+0.06	-3.3
1310	1281	1961 May	08	58	35.8	14	46	42.17	+0.05	-3.2
1311	1289	1961 May	09	58	27.8	15	00	01.09	+0.03	-2.7
1312	1315	1961 Jul	06	59	89.6	19	05	39.61	+0.04	-2.9

TABLE II

No.	Comparison Stars		Dependences			
1150	Yale 12	I 6905, 6908, 6916	0.29970	0.30382	0.39648	S
1151	Yale 12	I 6844, 6849, 6869	0.44997	0.34465	0.20538	W
1152	Yale 16	8144, 8176, 11 8055	0.39868	0.54827	0.05305	S
1153	Yale 11	7931, 7942, 7960	0.31084	0.31958	0.36958	S
1154	Cape 19	6964, 6976, 7014	0.34717	0.49724	0.15560	S
1155	Cape Ft.	16539, 16560, 16676	0.57346	0.18026	0.24628	R
1156	Yale 12	I 7678, 7694, 7700	0.28191	0.39641	0.32169	R
1157	Yale 12	I 7664, 7688, 7695	0.13214	0.53500	0.33286	R
1158	Yale 14	13708, 13712, 13732	0.39578	0.33202	0.27220	S
1159	Yale 14	13629, 13631, 13659	0.46947	0.31708	0.21345	W
1160	Cape 17	8949, 8961, 9011	0.41481	0.20046	0.38473	S
1161	Cape 17	8826, 8860, 8876	0.28442	0.37979	0.33578	R
1162	Cord. D	11345, 11349, 11390	0.40008	0.17751	0.42241	W
1163	Cord. D	10995, 11068, 11070	0.27434	0.20969	0.51597	W
1164	Cord. D	10897, 10934, 10973	0.22415	0.36318	0.41267	R
1165	Yale 17	196, 210, 228	0.20171	0.36401	0.43428	R
1166	Yale 11	7806, 7814, 7828	0.19787	0.45527	0.34686	R
1167	Yale 12	II 6320, 6337, 12 I 5633	0.21904	0.32298	0.45798	S
1168	Yale 12	II 7028, 12 I 6157, 6184	0.46467	0.28758	0.24775	W
1169	Yale 12	I 6112, 6136, 12 II 6988	0.46277	0.27111	0.26612	R
1170	Yale 16	5082, 5086, 5097	0.56349	0.26930	0.16721	R
1171	Yale 16	5013, 5033, 5040	0.17898	0.31975	0.50127	W
1172	Yale 14	15815, 15824, 15844	0.32064	0.31528	0.36408	R
1173	Yale 11	5139, 5147, 5153	0.42956	-0.38207	0.95251	S
1174	Yale 11	5079, 5087, 5094	0.13488	0.51685	0.34827	R
1175	Yale 12	II 6321, 6322, 6336	0.26986	0.23370	0.49644	S
1176	Yale 12	I 7515, 7562, 12 II 8582	0.33644	0.32632	0.33724	S
1177	Cape 18	10844, 10845, 10874	0.12013	0.60270	0.27718	R
1178	Cape 17	11184, 11185, 11226	0.28994	0.40749	0.30257	S
1179	Yale 13	II 12929, 12951, 12971	0.26120	0.48906	0.24973	R
1180	Cape 17	10614, 10634, 10637	0.33464	0.27809	0.38727	W
1181	Yale 14	13622, 13646, 13651	0.33468	0.25017	0.41515	R
1182	Yale 14	13293, 13307, 13330	0.30242	0.45184	0.24574	S
1183	Yale 17	6910, 6931, 6934	0.19264	0.49416	0.31320	W
1184	Yale 16	6215, 6225, 6231	0.41363	0.34712	0.23926	R
1185	Yale 16	6195, 6196, 6212	0.20880	0.53512	0.25608	S
1186	Yale 11	8057, 8064, 8073	0.26881	0.14801	0.58317	S

TABLE II—*continued*

No.	Comparison Stars	Dependences			
1187	Yale 11 7882, 7887, 7911	0·47178	0·20804	0·32018	S
1188	Yale 14 11544, 11551, 11559	0·56372	0·23797	0·19831	S
1189	Yale 14 11372, 11377, 11396	0·23021	0·30854	0·46125	W
1190	Yale 14 12785, 12798, 12822	0·37373	0·23041	0·39586	W
1191	Yale 14 12437, 12467, 12502	0·22648	0·36421	0·40931	R
1192	Yale 11 4868, 4877, 4885	0·30922	0·46366	0·22712	R
1193	Yale 16 4823, 11 4814, 4829	0·32215	0·34768	0·33017	R
1194	Yale 12 I 5573, 5591, 5595	0·57191	0·24941	0·17868	S
1195	Yale 12 I 5195, 5204, 5208	0·16160	0·19630	0·64210	R
1196	Yale 12 I 5182, 5199, 11 4893	0·25153	0·42132	0·32715	S
1197	Yale 13 II 10839, 10856, 10866	0·36071	0·20863	0·43066	R
1198	Yale 13 II 10480, 10523, 10524	0·36644	0·17656	0·45700	R
1199	Yale 11 5140, 5155, 5165	0·21030	0·55306	0·23665	S
1200	Yale 11 5081, 5086, 5093	0·44016	0·31931	0·24053	R
1201	Yale 13 II 13582, 13591, 13597	0·22863	0·33158	0·43978	W
1202	Yale 11 8297, 8307, 16 8440	0·31183	0·34209	0·34608	S
1203	Cape 17 9261, 9293, 9311	0·58370	0·19763	0·21867	W
1204	Cape 17 9225, 9236, 9261	0·31404	0·33656	0·34934	R
1205	Yale 12 I 8196, 8198, 8210	0·06042	0·39066	0·54893	S
1206	Yale 11 7463, 7469, 7481	0·26211	0·39890	0·33900	S
1207	Yale 11 6935, 6959, 6965	0·27809	0·20508	0·51683	R
1208	Yale 11 6698, 6710, 6735	0·22041	0·39977	0·37982	R
1209	Yale 14 13169, 13178, 13205	0·19858	0·65917	0·14225	W
1210	Cape 18 9762, 9771, 9791	0·23831	0·43717	0·32453	S
1211	Cape 18 9559, 9562, 9584	0·46256	0·31140	0·22605	S
1212	Yale 11 4591, 4611, 16 4638	0·40920	0·25573	0·33507	R
1213	Yale 16 4584, 4587, 4596	0·31472	0·32571	0·35957	R
1214	Yale 14 10132, 10167, 10182	0·28105	0·38680	0·33215	R
1215	Yale 14 10117, 10120, 10132	0·27937	0·54713	0·17351	S
1216	Yale 14 10061, 10071, 10097	0·30885	0·38375	0·30741	W
1217	Yale 11 8178, 8186, 8191	0·43464	0·13691	0·42845	S
1218	Yale 12 I 8514, 8534, 8540	0·24311	0·42276	0·33413	R
1219	Yale 16 5529, 5545, 5549	0·52974	0·21665	0·25362	R
1220	Yale 16 5442, 5445, 5455	0·15250	0·56491	0·28259	S
1221	Yale 12 II 64, 68, 74	0·19774	0·64722	0·15504	R
1222	Yale 12 II 9953, 9961, 9979	0·40449	0·40789	0·18762	S
1223	Yale 13 II 969, 984, 1000	0·39244	0·31093	0·29663	R
1224	Yale 13 II 894, 895, 908	0·47597	0·34019	0·18384	W
1225	Yale 12 I 7629, 7635, 7652	0·43596	0·23748	0·32656	R
1226	Yale 12 I 7576, 7578, 7596	0·23241	0·41801	0·34958	S
1227	Yale 16 5636, 5654, 5660	0·26147	0·37123	0·36730	R
1228	Yale 16 5564, 5580, 5582	0·45672	0·34743	0·19585	R
1229	Cape 17 10526, 10551, 10574	0·42251	0·43968	0·13781	R
1230	Cape 18 9807, 9813, 9838	0·19061	0·43468	0·37471	R
1231	Yale 12 I 433, 434, 445	0·28316	0·18060	0·53624	S
1232	Yale 12 I 391, 394, 411	0·40719	0·36765	0·22516	R
1233	Yale 12 I 8801, 8807, 8815	0·27838	0·40102	0·32060	R
1234	Yale 12 I 8720, 8728, 8735	0·16372	0·20525	0·63102	R
1235	Yale 12 I 7615, 7637, 7651	0·28587	0·36129	0·35284	R
1236	Yale 12 I 7592, 7594, 7607	0·47294	0·30266	0·22440	S
1237	Cape 17 10099, 10110, 10145	0·18853	0·41153	0·39994	R
1238	Cape 17 9827, 9835, 9896	0·30161	0·38693	0·31146	R
1239	Yale 12 II 6387, 6389, 6410	0·36080	0·40896	0·23024	S
1240	Yale 12 II 6316, 6318, 6337	0·51020	0·34011	0·14969	R
1241	Yale 13 I 83, 100, 105	0·08941	0·28515	0·62544	R
1242	Yale 14 15971, 5, 13	0·24866	0·54244	0·20890	S
1243	Yale 14 10125, 10149, 10151	0·33774	0·47653	0·18573	S
1244	Yale 14 10071, 10088, 10101	0·20438	0·48164	0·31398	W
1245	Yale 14 11664, 11679, 11706	0·43515	0·20455	0·36030	R
1246	Yale 14 11615, 11646, 11664	0·26261	0·19064	0·54674	S
1247	Yale 14 11430, 11442, 11450	0·29686	0·26262	0·44052	W
1248	Cape 17 10532, 10551, 10559	0·20539	0·64145	0·15316	R
1249	Yale 12 I 7979, 7980, 8010	0·31138	0·50225	0·18637	S
1250	Yale 14 10152, 10167, 10182	0·40849	0·25403	0·33748	W
1251	Cape 17 8318, 8319, 8339	0·10728	0·28093	0·61179	S
1252	Cape 17 8000, 8016, 8026	0·19172	0·24896	0·55932	R

TABLE II—*continued*

No.	Comparison Stars		Dependences			
1253	Yale 14	12827, 12845, 12886	0·28672	0·41947	0·29380	W
1254	Yale 13 II	11685, 11717, 14 12505	0·24668	0·18661	0·56670	R
1255	Yale 12 I	7711, 7712, 7745	0·44483	0·24892	0·30626	S
1256	Yale 12 I	7678, 7680, 7712	0·36183	0·32339	0·31478	W
1257	Yale 16	8176, 8211, 11 8088	0·24018	0·55029	0·20953	S
1258	Yale 12 I	8188, 8189, 8196	0·36351	0·45722	0·17926	S
1259	Yale 12 I	8188, 8190, 8198	0·41880	0·09278	0·48843	S
1260	Yale 14	11616, 11627, 11634	0·36826	0·14895	0·48279	R
1261	Yale 14	11582, 11596, 11634	0·28281	0·47490	0·24229	S
1262	Yale 14	11406, 11430, 11442	0·30450	0·33096	0·36455	W
1263	Yale 13 I	8578, 8612, 8615	0·53463	—0·03385	0·49922	S
1264	Yale 14	13798, 13826, 13830	0·43712	0·24582	0·31706	R
1265	Yale 14	13500, 13552, 13561	0·28331	0·46164	0·25505	W
1266	Yale 14	13121, 13147, 13174	0·29616	0·56987	0·13397	S
1267	Cape Ft.	18480, 18519, 18531	0·19455	0·48107	0·32438	R
1268	Cape Ft.	18380, 18394, 18460	0·34650	0·26268	0·39082	R
1269	Yale 17	5485, 5491, 5511	0·24251	0·37636	0·38113	R
1270	Yale 12 I	108, 121, 128	0·28489	0·36746	0·34765	R
1271	Yale 16	253, 258, 266	0·65501	0·15111	0·19388	R
1272	Yale 11	159, 160, 181	0·35724	0·34987	0·29289	R
1273	Yale 13 I	8, 15, 24	0·07507	0·60550	0·31943	R
1274	Cape 17	9193, 9214, 9223	0·31846	0·37615	0·30539	W
1275	Cape 17	9145, 9182, 9189	0·31395	0·32667	0·35938	R
1276	Yale 12 I	8002, 8005, 8020	0·28885	0·40869	0·30247	S
1277	Yale 21	5843, 5847, 5854	0·28485	0·27196	0·44318	S
1278	Yale 17	7976, 7986, 7990	0·16326	0·40706	0·42968	S
1279	Yale 11	8051, 8055, 8065	0·26670	0·44254	0·29076	S
1280	Yale 11	7918, 7945, 7950	0·33697	0·27302	0·39001	S
1281	Yale 13 II	13391, 13412, 13424	0·30306	0·37221	0·32472	S
1282	Yale 14	13714, 13739, 13749	0·36687	0·45539	0·17773	S
1283	Yale 12 I	189, 197, 199	0·24870	0·31914	0·43216	W
1284	Yale 13 I	85, 12 II 98, 110	0·54312	0·21773	0·23915	R
1285	Yale 17	485, 496, 498	0·26249	0·55332	0·18419	R
1286	Yale 12 I	7701, 7705, 7721	0·37499	0·42043	0·20458	S
1287	Yale 12 I	7666, 7667, 7685	0·45352	0·16749	0·37899	W
1288	Cape 18	7667, 7690, 7694	0·35701	0·46344	0·17955	R
1289	Yale 14	10173, 10183, 10190	0·30492	0·42172	0·27336	S
1290	Yale 14	10108, 10130, 10135	0·18056	0·52991	0·28953	W
1291	Yale 13 I	9130, 9158, 14 14722	0·25878	0·26139	0·47983	S
1292	Yale 13 I	8977, 9007, 9017	0·32928	0·33901	0·33170	S
1293	Yale 13 I	8913, 8915, 8926	0·33008	0·36974	0·30017	W
1294	Cape 18	7667, 7669, 7701	0·37124	0·27287	0·35589	R
1295	Cape 18	7473, 7495, 7505	0·28843	0·37953	0·33204	R
1296	Cape 18	7358, 7375, 7394	0·24734	0·46295	0·28971	W
1297	Yale 12 I	6440, 6462, 6465	0·14108	0·27134	0·58758	S
1298	Yale 12 I	6375, 6387, 6399	0·26405	0·21997	0·51598	R
1299	Yale 12 II	9403, 9406, 9425	0·32661	0·38902	0·28437	S
1300	Cord. D	16047, 16056, 16090	0·29547	0·37022	0·33432	S
1301	Yale 11	7806, 7814, 7819	0·28347	0·22672	0·48981	S
1302	Yale 12 I	8189, 8198, 8208	0·26463	0·34215	0·39322	W
1303	Yale 11	707, 720, 729	0·22431	0·30129	0·47440	R
1304	Yale 11	633, 639, 648	0·40054	0·30874	0·29072	S
1305	Yale 16	5651, 5661, 5670	0·17012	0·64574	0·18414	W
1306	Yale 17	5523, 5534, 5545	0·13754	0·56533	0·29712	R
1307	Yale 12 I	6931, 6937, 6951	0·21885	0·43442	0·34673	S
1308	Yale 11	41, 46, 49	0·39906	0·16117	0·43977	R
1309	Yale 11	8312, 8314, 8322	0·43875	0·40947	0·15178	R
1310	Yale 11	5191, 5197, 5217	0·46581	0·28461	0·24958	S
1311	Yale 12 I	5539, 5547, 5550	0·21760	0·60678	0·17562	S
1312	Yale 12 I	7072, 7102, 7106	0·24573	0·34919	0·40508	R

(Received 27 February 1962)

Occultations Observed at Sydney Observatory during 1961

K. P. SIMS
Sydney Observatory, Sydney

The following observations of occultations were made at Sydney Observatory with the 11½ inch telescope. A tapping key was used to record the times on a chronograph. The reduction elements were computed by the method given in the Occultation Supplement to the *Nautical Almanac* for 1938 and the reduction completed by the method given there. For 1961 a correction of +0.00944 hour (=34

seconds) was applied to the observed time to convert it to ephemeris time with which *The Astronomical Ephemeris for 1961* was entered to obtain the position and parallax of the Moon. The apparent places of the stars of the 1961 occultations were provided by H.M. Nautical Almanac Office.

Table I gives the observational material. The serial numbers follow on from those of the

TABLE I

Serial No.	Z.C. No.	Mag.	Date	U.T.	Observer
409	3437	6.7	Jan. 20	9 47 01.01	S
410	2454	7.2	Jul. 24	14 11 39.9	R
411	2460	6.1	Jul. 24	16 00 03.6	R
412	2578	6.4	Jul. 25	8 49 24.6	W
413	2113	7.0	Aug. 18	10 44 56.1	S
414	2680	5.8	Aug. 22	8 00 39.3	W
415	2685	7.0	Aug. 22	8 35 04.5	W
416	2687	7.3	Aug. 22	9 13 42.8	W
417	2649	6.9	Sep. 18	12 58 26.6	R
418	....	8.5	Sep. 18	13 02 51.7	R
419	....	9.0	Sep. 18	13 03 58.0	R
420	2653	6.4	Sep. 18	13 26 24.2	R
421	....	8.0	Sep. 18	13 26 59.9	R
422	2828	6.0	Sep. 19	14 55 37.5	R
423	2715	6.5	Nov. 12	10 40 47.8	R
424	....	9.0	Nov. 12	10 48 23.0	R

TABLE II

Serial No.	Lunation No.	p	q	p ²	pq	q ²	Δσ	pΔσ	qΔσ	Coefficient of	
										Δα	Δδ
409	471	+ 90	-43	81	-39	19	-0.2	-0.2	+0.1	+14.8	-0.13
410	477	+ 97	+26	93	+25	7	-0.8	-0.8	-0.2	+14.2	+0.14
411	477	+100	- 7	100	- 7	0	-0.6	-0.6	0.0	+14.0	-0.19
412	477	+ 64	-77	41	-49	59	-0.4	-0.3	+0.3	+ 8.4	-0.81
413	478	+ 76	-65	58	-49	42	+1.2	+0.9	-0.8	+ 8.2	+0.83
414	478	+ 89	+45	80	+40	20	-1.5	-1.3	-0.7	+12.8	+0.43
415	478	+ 99	-12	99	-12	1	+0.7	+0.7	-0.1	+14.1	-0.13
416	478	+ 53	-85	28	-45	72	+1.5	+0.8	-1.3	+ 7.5	-0.85
417	479	+100	- 6	100	- 6	0	-0.9	-0.9	+0.1	+14.1	-0.09
418	479	+ 96	+28	92	+27	8	+0.2	+0.2	+0.1	+13.7	+0.26
419	479	+100	+ 6	100	+ 6	0	+2.6	+2.6	+0.2	+14.2	+0.03
420	479	+ 86	+51	74	+44	26	-0.6	-0.5	-0.3	+12.3	+0.49
421	479	+ 88	-48	77	-42	23	-2.0	-1.8	+1.0	+12.3	-0.50
422	479	+100	- 3	100	- 3	0	-1.2	-1.2	0.0	+14.2	+0.04
423	481	+ 86	-51	74	-44	26	+0.2	+0.2	-0.1	+12.3	-0.50
424	481	+ 94	-33	89	-31	11	-2.6	-2.4	+0.9	+13.4	-0.32

previous report (Sims, 1961). The observers were W. H. Robertson (R), K. P. Sims (S), and H. W. Wood (W). In all cases the phase observed was disappearance at the dark limb. Table II gives the results of the reductions which were carried out in duplicate. The Z.C. numbers given are those of the *Catalog of 3539 Zodiacal Stars for the Equinox 1950.0* (Robertson, 1940).

The stars involved in occultations 418, 419, 421 and 424 were not in Z.C. They are

Yale 12 II 7605, Yale 12 II 7607, G.C. 24979 and Yale 12 II 7858. Their apparent places are R.A. $18^{\text{h}} 15^{\text{m}} 42^{\text{s}}.89$, Dec. $-18^{\circ} 42' 56''.4$; R.A. $18^{\text{h}} 15^{\text{m}} 47^{\text{s}}.72$, Dec. $-18^{\circ} 46' 32''.8$; R.A. $18^{\text{h}} 16^{\text{m}} 28^{\text{s}}.71$, Dec. $-18^{\circ} 37' 50''.9$; R.A. $18^{\text{h}} 41^{\text{m}} 01^{\text{s}}.60$, Dec. $-19^{\circ} 15' 49''.4$.

References

- ROBERTSON, A. J., 1940. *Astronomical Papers of the American Ephemeris*, Vol. X, Part II.
SIMS, K. P., 1961. *J. Proc. Roy. Soc. N.S.W.*, **95**, 123; *Sydney Observatory Papers*, **40**.

Nucleic Acids, Their Structure and Function*

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Introduction

Mr. President, Ladies and Gentlemen,

I would like to thank the Council of the Royal Society of New South Wales for the honour they have conferred on me by inviting me to give the Liversidge Lecture for 1962. In his will, Archibald Liversidge refers to the "vastness of the subject", the subject being chemistry, and in my lecture this evening I have chosen a subject which well illustrates the vast scope of modern chemistry. The great progress in our knowledge of nucleic acids has only come during the last twenty years through the application of a great number of techniques, chemical, physical, biochemical and biological. These techniques have all been aimed at determining the structure and behaviour of nucleic acids at the molecular level, or in other words, at their *chemical* structure and behaviour. In another part of his will, Liversidge directs the lecturers not to give "popular lectures dealing with generalities and giving mere reviews of their subjects", but rather that they should "primarily encourage research and stimulate the lecturer and the public". Although part of my lecture might almost be classified as a review, I trust that this will not be contrary to the directions of Liversidge. The development of our knowledge of the nucleic acids over the last two decades affords almost a perfect example of how the parallel contributions of organic chemistry, physical chemistry, biochemistry, biology and genetics can contribute to the solution of a single problem.

It is just over twenty years ago since the late Professor J. M. Gulland, F.R.S., persuaded me to investigate the physical chemistry of nucleic acids, and I would like to pay tribute to his encouragement at a time when our ideas on the macromolecular structure of nucleic acids were just developing. My own contribution to nucleic acid chemistry has been through the application of the methods of physical chemistry

to the problems of structure and behaviour and I trust that if I emphasize this aspect of nucleic acid chemistry tonight I will be acting in conformity with the wishes of Liversidge.

The discovery of nucleic acids was a result of work by Miescher in 1868 in Hoppe-Seyler's laboratory. It created particular interest because it was only the second organic compound known at that time containing phosphorus: the other being lecithin. The preparations of Miescher were undoubtedly of high molecular weight, although most probably not free of protein, and the early workers were fully aware of the care needed in preparation to preserve the macromolecular properties. However, at that time chemists were not prepared to accept high molecular weight substances as worthy of study and in 1899 Neumann described a preparation which involved the use of concentrated sodium hydroxide which was to set the pattern for preparations for the next thirty or forty years. There thus followed an intensive study of the chemistry of the breakdown products of nucleic acids and the study of the macromolecular structure had to await the development of new techniques which were initiated by the study of protein chemistry and the development of synthetic high polymer chemistry.

The Structure of the Nucleotides

The nucleic acids are copolymers of the nucleotides, which in many respects are analogous to the role played by amino acids in the proteins. The nucleotides are phosphoric esters of the nucleosides which are N-glycosides of purines and pyrimidines. All the main structural features of the nucleotides have been determined by the classical methods of organic chemistry through the work of Levene, Gulland, and more particularly Todd, who has achieved the chemical synthesis of all the main nucleotides.

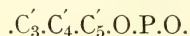
The nucleic acids fall into two main groups which differ in their chemical composition, their macromolecular structure and in biological

* Liversidge Research Lecture delivered on 19 June, 1962.

function. These are the deoxyribonucleic acids (DNA) and the ribonucleic acids (RNA). These are named after the sugar moiety which occurs in the two groups, 2-deoxy-D-ribose in one (DNA) and D-ribose in the other (RNA). In both nucleic acids it is usual to find at least four nucleotides, these being the phosphorylated N-D-ribosides of guanine, adenine, cytosine and uracil in RNA, and the phosphorylated N-2-deoxy-D-ribosides of guanine, adenine, cytosine and thymine (5-methyl uracil) in DNA. From the synthetic work of Todd and his collaborators (1944, 1947, 1951) and from the X-ray work of Furberg (1950) and Huber (1957) we know that the point of attachment of the sugar is at N₃ in the pyrimidines and at N₉ in the purines. The configuration of the glycosidic linkage is always β and the sugar is always in the furanose form. Other nucleotides have been isolated, generally in small amounts, from some nucleic acids, the incidence of these will have biological significance.

The Internucleotide Bond

Various possibilities exist for the linkage between the nucleotides, but from titration evidence all possibilities except that of a phosphoester linkage can be eliminated. This is confirmed by the isolation of the three isomeric 2', 3' and 5' phosphates of the ribonucleosides on chemical or enzymic hydrolysis of RNA and on the isolation of the 3' and 5' phosphates of the deoxyribonucleosides from DNA. In DNA the linkage is thus clearly a 3'-5' phosphoester linkage, whereas in RNA it could be a linkage between 2' or 3' and the 5' position, present evidence favours the 3'-5' linkage as in DNA. We thus see that the polymeric "backbone" of the molecules of RNA and DNA consists of a repeating unit of the following atoms



We may call this the primary structure of the nucleic acids.

The Secondary Structure of DNA

Our present ideas on the secondary structure of DNA stem largely from the structure suggested by Watson and Crick (1953, 1954). In the nine years that have elapsed since the introduction of this formula, only minor modifications have been made to the structure and it is now widely accepted as explaining the transfer of genetical characteristics at cell division although the full story is not yet known. The main features of this structure are: (1) the DNA molecule consists of a double helix con-

sisting of two polynucleotide *h*elices wound round a common axis; (2) the double helix is regular; (3) the two polynucleotide molecules are held together by hydrogen bonds, which by virtue of the regular nature of the double helix must be specific in that adenine is always bonded to thymine and guanine to cytosine (Fig. 1). Watson and Crick suggested only two hydrogen bonds in the guanine-cytosine base pair, but Pauling and Corey (1956) later pointed out that three bonds are possible.

In view of the importance of this structure, let us examine the experimental evidence on which it rests. The presence of hydrogen bonds between the bases was first suggested by Professor Gulland, Dr. Taylor and myself (1947) to explain the anomalous titration curve we observed with calf thymus DNA. When solutions of the sodium salt of DNA originally at pH 6-7 are first titrated to pH 2.5 or to pH 12, the titration curves differ markedly from the back titration curves. The addition of acid or alkali to the deoxyribonucleate does not at first bring about the ionization of acid and base groups and the unbuffered region in the initial titration curves extends from pH 4.5 to 11.0 compared with pH 6 to 9 in the back titration curve. Outside the pH range 4.5-11.0 a rapid liberation of groups occurs in the pH range 2.0 to 6.0 and 9.0 to 12.0. The same back titration curve is obtained whether the back-titration is commenced at pH 12 or 2.5. These observations were originally interpreted in the belief that the amino groups of guanine, adenine and cytosine were titrated in the range pH 2.0 to 6.0 whilst in the pH range 9.0 to 12.0 the -NH-CO- groups of guanine and thymine were dissociated. Whilst the latter assumption is still regarded as correct, it is almost certain that the ring nitrogens of the purines and pyrimidines are more basic than the amino groups. In the protonated form of adenine it has been established by X-ray and nuclear magnetic resonance studies that the proton is located at N₁ and not on the amino group, and the same result is reached from theoretical calculations (Broomhead, 1951; Cochran, 1951; Jardetzky and Jardetzky, 1960). The location of the proton on cytosine will also be at N₁, but in guanine since N₁ is already linked to hydrogen, the -NH-CO- group being in the keto form, the proton most probably is attached to N₇ or the amino group. In spite of the change of viewpoint concerning the groups titrated in the acid range, the interpretation that the groups titrated in the two ranges were linked by hydrogen bonds

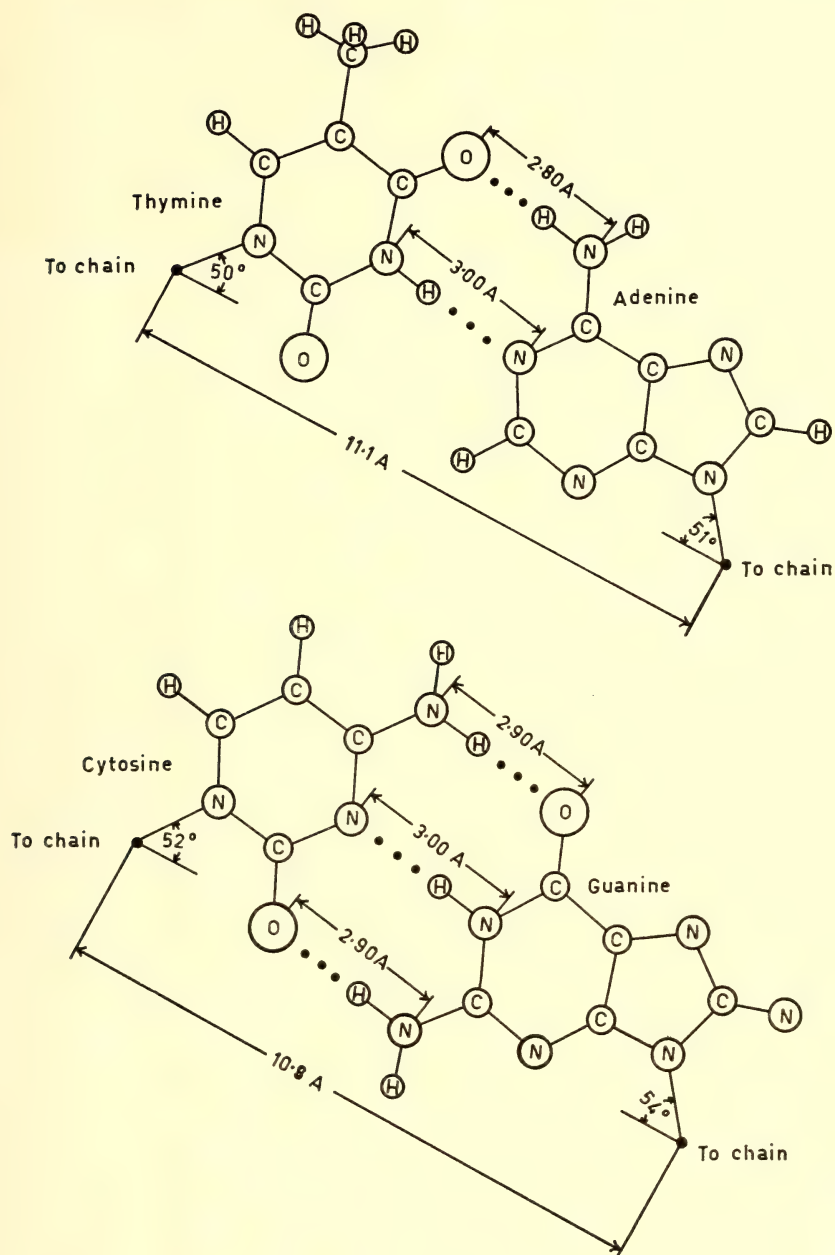


FIG. 1

which thus weakened the dissociation of the groups is still valid. That the bonds were intermolecular and not intramolecular was determined by viscosity and streaming birefringence studies (Creeth, Gulland and Jordan, 1947; Mathieson and Matty, 1957). A very marked decrease in the viscosity and streaming birefringence was observed at those pH values

where the ionization of the groups occurred. This result could be explained only by a breakdown of the hydrogen bonded structure to yield either smaller molecular units or a less asymmetric molecule.

More detailed information on the structure of DNA comes from the X-ray studies of the Randall and Wilkins group at King's College,

London. Franklin and Gosling (1953), using oriented fibres of DNA, produced by withdrawing a fibre slowly from a concentrated solution at constant humidity, obtained good X-ray diffraction patterns for sodium deoxyribonucleate. More recently more detailed patterns have been obtained with the lithium salt (Wilkins, Langridge, Wilson, Hooper and Hamilton, 1960). From the analysis of the diffraction pattern, and in particular from the cylindrical Patterson function, it was evident that the model consisted of a regular double helix and the essential parameters could be deduced, the distance between the nucleotide residues is 3.4 Å, the repeat of the helix occurred every 34 Å or ten nucleotides, and the diameter is 17 Å. These dimensions are dependent on the water content of the fibre but are unlikely to be greatly different in solution.

The contribution made by Watson and Crick, which led to the well known formula, arose from attempts to construct models of DNA. In order to do this it was necessary to know the structure and configuration of the nucleotides. Previous attempts to construct a model of a nucleotide by Astbury and others had been made on the assumption that the purine or pyrimidine ring lay in the same plane as the sugar ring. This was shown not to be so by Furberg (1950), who determined the structure of cytidine (cytosine-*N*-riboside) and showed that the angle between the rings was almost a right angle. On this basis Furberg (1952) had constructed models of nucleic acid which were single stranded and showed that the chain was twisted in the form of a helix. By extending this structure to the double helix and introducing the specific hydrogen bonds Watson and Crick were able to obtain their structure. That this structure is maintained in aqueous solution has been demonstrated by the small angle X-ray scattering studies of Luzzati, Nicolaieff and Masson (1961).

The specific pairing of the bases in the hydrogen bonded double helix carries with it the implication that for every guanine residue in the DNA molecule there must be an exactly equivalent number of cytosine residues. Similarly adenine and thymine must be present in equivalent amounts. The analytical figures for a large number of samples of DNA show that this is approximately true even though, in nucleic acids from different samples, the ratio of adenine to guanine can vary very considerably. This had been observed by Chargaff (1950) who, prior to the publication of the Watson and Crick structure, had suggested

the specific pairing of guanine and cytosine and adenine and thymine in DNA.

Before leaving this discussion, we should consider possible modifications of the Watson and Crick structure. The main possibility is that instead of the two polynucleotide chains in the double helix being continuous, they possess random or specific breaks. Such breaks would not affect the X-ray structure and if occurring at less frequent intervals than once every twenty or thirty nucleotides, could not be detected by titration. Experimental evidence that such breaks do occur has been produced by Dekker and Schachman (1954) from enzymic degradation studies. However, molecular weight studies on the native and denatured DNA do not agree with this view and it is now generally believed that such breaks, if they occur, are artifacts produced during preparation and that in the native material the two intertwined strands are continuous.

Size and Shape of DNA

DNA is a polyelectrolyte inasmuch as it possesses two charged phosphate groups every 3.4 Å along the chain. Synthetic polyelectrolytes such as polymethacrylic acid show marked changes in shape on charging and discharging, being approximately rigid rods when charged and random coils when discharged. However, the presence of the hydrogen bonds and other interactions between the chains greatly modifies the expected polyelectrolyte behaviour with the result that DNA polyion behaves in solution as a stiff rod. Even when discharged, in high concentrations of sodium chloride, there is no collapse of the polyion to the random coil form. On denaturing, however, and the rupturing of the bonds between the chains, the stiffness is lost and single stranded DNA, either produced from twin stranded DNA by denaturation, or from the Φ X174 virus of Sinsheimer, shows normal polyelectrolyte behaviour. The stiffness of the DNA double helix is demonstrated by the viscosity data at zero shear in various solutions of sodium chloride obtained by Dr. Porter (1960).

The molecular weight of DNA samples has been regarded until recently to lie in the range $6-10 \times 10^6$. Such values have generally been obtained from light scattering data or from a combination of sedimentation coefficient and either diffusion or viscosity values. However, recently it has become clear that even these values are too low and that the DNA in the cell possesses molecular weights more in the region of 110×10^6 or higher. Dr. Cairns (1961), by

using an extremely mild technique, has been able to isolate DNA in this way and by labelling the DNA with tritium to determine the molecular weight autoradiographically. It has been known for some time that long molecules may be reduced in length by placing them in a shear gradient and the chemist has yet to learn how to handle these very long asymmetric molecules.

One of the most important discoveries which has greatly aided the study of nucleic acids in recent years was made as far back as 1944, when Avery, Macleod and McCarty (1944) isolated transforming DNA. This biologically active DNA transforms one bacterial cell type into another. This property has been investigated and transforming DNA has now been isolated from many different bacteria.

Denaturation of DNA

If, as we believe, the DNA twin helix separates during cell division and each strand acts as a template for the synthesis of a second strand of DNA to complete the double helix, the study of the denaturation of DNA is of great importance. I shall now discuss the various ways in which DNA can be denatured and the mechanism of the various processes.

DNA may be denatured in aqueous solution by (a) heat, (b) acid or alkali, and (c) solution in very dilute solutions in the absence of sodium chloride. It is worth noting here that ultrasonic degradation does not denature DNA and that γ irradiation also does not denature DNA. Both these forms of radiation produce covalent bond breakage, generally of both chains, so that the DNA is broken down into undenatured smaller fragments. However, in some circumstances denaturation can occur and the behaviour is very dependent on the extent of the irradiation and its intensity.

The heat denaturation of DNA may be brought about by heating the DNA in solution above a certain critical temperature. Zamenhof, Alexander and Leidy (1953) were the first to observe that the viscosity of DNA solutions remained constant as temperature was increased until a certain critical temperature is reached, when the viscosity falls rapidly with further increase of temperature. The activity of transforming DNA also falls at the same temperature. Instead of observing the viscosity, it is preferable, and certainly more convenient, to follow the change in optical density. The ultraviolet absorption of DNA at 259 m μ is much less than that calculated from the known absorption coefficients of the nucleotides. This hyperchromic effect is believed to be due to the

interaction between the purines and pyrimidines stacked one above the other in the double helix. Removal of the hydrogen bonded structure markedly reduces the hyperchromic effect and the absorption markedly increases. Thus following the absorption at 259 m μ is a very convenient way of determining the denaturation or "melting" temperature. This temperature is related to the composition of the DNA, those possessing a high guanine and cytosine content have high melting points, and those with a high adenine-thymine content, low melting points. The denaturation process is analogous to the melting of a hydrogen bonded crystal in which the structure passes from the ordered arrangement in the crystal to the disordered state in the melt. On denaturing DNA we pass from the ordered Watson-Crick structure to the random coils of single or intertwined polynucleotide chains with an analogous entropy change to that occurring in the melting of the crystal. As the temperature is increased, the kinetic energy of the segments of the DNA molecule will also increase until the energy is sufficient to overcome the interaction energy.

Although the denaturation by acid and alkali was observed first, since the titration curves illustrate irreversible denaturation, we know less about the mechanism than we do for other methods. The effect of acid or alkali addition is to affect the N \cdots H-N bonds of the adenine to thymine and guanine to cytosine base pairs, addition of protons or removal of protons will produce positively or negatively charged nitrogen atoms respectively, but will only bring about the rupture of one hydrogen bond, the other bond in the adenine-thymine pair and the other two in the guanine-cytosine pair remaining unaffected. It is difficult to see immediately whether this will be sufficient to lead to dissociation. However, it must be remembered that dissociation by heat cannot be neglected and both these forms of denaturation will be present at the same time. Thus Cavalieri and Rosenberg (1957) have shown that as the temperature is increased it is necessary to titrate less groups in the acid region (and the same will occur in the alkaline region) to produce denaturation.

The last method of denaturation is one which Dr. Inman and I (1960) investigated a year or so ago. Thomas (1954) showed that if sodium chloride was removed from a solution of DNA the optical density increased and on increasing the sodium chloride concentration again the optical density, although reduced, did not return to the original low value. This process he described

as denaturation; he was, in fact, the first to apply this term to nucleic acids. Dr. Inman and I were able to show that denaturation occurred on reducing the DNA concentration of a salt-free solution and if this was followed either by the change in conductivity or by the change in optical density a critical concentration was observed at which denaturation occurred. This critical concentration was dependent on the electrolyte concentration, in agreement with the findings of Thomas. The mechanism of this method of denaturation is most probably that of electrostatic repulsion between the charged groups of the two polynucleotide chains. The effective charge on the phosphate groups will vary with the counterion concentration and dilution of the DNA or removal of electrolyte will bring about the dissociation of the ion pairs which exist at higher concentrations, the charge will thus increase until at infinite dilution the phosphate groups are fully charged. The repulsion energy between the charged groups can be calculated as a function of the charge fraction and from the experimentally determined value of the charge fraction at the critical concentration we can obtain the bonding energy per phosphorus atom; this comes out to be 3.1 k.cals., which is not unreasonable for 1 to 1.5 hydrogen bonds per phosphate group.

Protein denaturing agents such as urea and guanidine hydrochloride do not denature DNA, but do aid denaturation by other means. Thus the melting temperature is lowered in the presence of 8M urea.

The Reversibility of DNA Denaturation

From early studies of the denaturation of calf thymus DNA, it was concluded that the denaturation process was irreversible and the double helix gave an intertwined random coil which could contain some non-specific hydrogen bonds. However, with the realization that the sequence of nucleotides determines the genetic code, it became appreciated that the likelihood of producing reversible denaturation was dependent on having a nucleic acid preparation which did not contain too many different kinds of genetically, and therefore chemically, different DNA. The DNA from mammalian glands such as calf thymus is very complex as has been shown by the fractionation work of Bendich, which has been confirmed and extended by Mr. Colvill and myself. Whether this fractionation is the type which is genetically significant, I very much doubt, but it nevertheless shows that the DNA is complex. Bacterial DNA is less complex genetically and has the advantage

of being biologically active, virus DNA would be simpler still since each virus contains only one DNA molecule. The very brilliant researches of Doty (1961) have demonstrated beyond doubt that bacterial DNA can be denatured reversibly. The process used is a simple and obvious one. We have already likened the denaturation by heat to a melting of a crystal, so the reverse process of renaturation should be possible by a process akin to crystallization. Heat denaturation followed by a slow cooling should therefore reproduce native DNA. This is what Doty observed. The slow cooling process allows the individual polynucleotide chains to seek out their partners in the solutions and form the specific hydrogen bonds with the complementary sequence. DNA which has been denatured by heat and slowly cooled is found to regain its original melting temperature and also much of its original biological activity.

Renaturation of DNA in this way does not necessarily involve strand separation during the denaturation process. That strand separation does occur was brilliantly proved by Doty (1961) by using two preparations of DNA obtained from the same bacteria, one grown on media containing N^{14} and H^1 and the other N^{15} and D. Such DNA's can be separated analytically by the technique of density gradient ultracentrifugation. A mixture of N^{14} and N^{15} labelled DNA was heated so as to produce denaturation; if strand separation *did not* occur only two species would result, but if strand separation *did* occur five species would result, viz. single strand N^{14} , double strand N^{14} , double strand hybrid N^{14}, N^{15} , single strand N^{15} , and double strand N^{15} . Five strands were observed in density gradient ultracentrifugation and if the renatured solution was treated with an enzyme which hydrolyses only single strand DNA, the single stranded moieties are removed and also any single strand "tails" at the ends of double strands. Three sharp fractions of the double stranded molecule are then obtained.

The Rate of Denaturation

Now that the mechanism of the denaturation process is firmly established, the rate of this process and the renaturation process warrants examination. Kinetic studies on the denaturation and renaturation of DNA have not been made, but Sturtevant and Ross (1960) have shown that the reaction between synthetic polyadenylic acid and polyuridylic acid is very rapid. In this reaction there is no slow process such as there is in DNA renaturation when the DNA strands have to seek the complementary

sequence, since any adenylic acid residues on one chain can bond to a uridylic acid residue on the other. However, it does show that the formation of the double helix can be a rapid process. From theoretical considerations, Kuhn (1961) and Longuet-Higgins and Zimm (1961) have concluded that a Watson-Crick helix can unwind by partial rotational or torsional Brownian movement round the axis in 50 to 80 seconds. In the renaturation process, there is not only the problem of forming the helix which is rapid, as shown by the formation of the polyadenylic acid-polyuridylic acid complex, but also the problem of forming the helix of minimum free energy which will have the maximum interaction between the strands.

The Macro Structure of RNA

Compared to DNA, our knowledge of the structure of RNA is still rather rudimentary, evidence exists for the formation of both single stranded and double stranded RNA. In the single stranded RNA there is also evidence for twin stranded sections, but whether these are biologically important or artifacts formed due to the ease of helix formation, is not clear.

Future Work

In his will, Archibald Livversidge directs the lecturer to draw "attention to the research work which should be undertaken". In the nucleic acid field, immense possibilities exist and I will confine my comments to those aspects which we are developing. One of the main difficulties confronting a physical chemist in nucleic acid chemistry is the difficulty that arises in handling a large, charged macromolecule in aqueous solution. Some years ago it was observed that the cetyl trimethyl ammonium salts of DNA were soluble in non-aqueous solvents and recently it has been shown that these salts can be reversibly formed from nucleic acids and polynucleotides. This opens up the possibility of making studies in non-aqueous media. We expect this technique to help greatly in the elucidation of the size and shape studies and also in the study of denaturation mechanism. We are furthering our studies of denaturation by extending the dilution method to other nucleic acids and have already observed that the critical concentration is dependent on composition. Much can be done with rapid reaction techniques on denaturation and renaturation mechanisms and we are particularly interested in the possibilities of studying reactions by suddenly altering the environment, either as regards concentration or temperature.

Then there is the problem of fractionation. Procedures so far have employed basic columns which have thus used only phosphate groups as points of attachment. Fractionation has thus largely been concerned with molecular size. What is required is a surface which will specifically adsorb only certain DNA molecules. Perhaps the answer is DNA supported on cellulose or combined and held in an oriented structure by some other means. It is important to realize that the problem of fractionation must be completely mastered before sequence determinations will have any significance.

A knowledge of the precise location of the protons is protonated DNA and polynucleotides in solution is required before the mechanism of acid and alkali denaturation can be elucidated. We hope nuclear magnetic resonance will help us here. We also have to learn how to handle large, asymmetric molecules such as have been isolated by Dr. Cairns, since subjecting these to even low shear gradients causes degradation.

Finally, there remains the problem of the small chemical difference between DNA and RNA which appears to cause a fundamental difference in the biological function. There is thus much to do; the main problem therefore is what should be done first. This emphasizes the most important aspect of research, the proper design of meaningful experiments.

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Some Chemical and Scientific Problems of the Late Twentieth Century*

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Many of my predecessors in office have taken the traditional Presidential Address as an opportunity to review or summarize the investigations with which they and their associates had been actively engaged. The rules of our Society, however, give the President no instruction on the matter, and I propose to reject the temptation to talk about the particular research fields now being explored by my collaborators and me within the Chemistry School of the University of Sydney.

There are a number of reasons for this decision. Firstly, only eighteen months ago you appointed me to be the "Liversidge Research Lecturer" for 1960 and the (printed) text of my lecture describes the main lines of work now proceeding; secondly, I believe the chief *raison d'être* of the Royal Society of New South Wales today to be the encouragement of a catholic attitude to science, and specialist topics at its meetings are no longer appropriate, necessary, or popular; and thirdly, there are problems looming which endanger all scientists, as such and as members of the human race, before which our daily and separate interests and preoccupations seem to lose some of their significance or justification.

Before speaking about such questions let me make a few remarks on the general state of chemistry. As a branch of science its growth has been orthodox: from prehistoric technology and observation came perceptual data from which the synthetical and analytical operations of human minds formulated conceptual schemes (theories) which in turn suggested experimentation the results of which, when unexpected, led to revised conceptual schemes; so by many repetitions of such cycles chemistry with the rest of science has become the comprehensive network of more or less correlated facts and theories we know today. During the first seven thousand years progress was slight; modern chemistry is the fruit of three centuries only. As Read said in 1947, "Alchemy was static. Chemistry is dynamic. Never, in the

whole gamut of intellectual and practical achievement, has mankind made a greater advance than in chemistry, in so short a time."

Actually its growth rate over the last 150 years has had an exponential character. A central theme through this period has been the development, from vague ideas of atoms and the ways they combine together, of detailed and quantitative theories of molecular structure. In 1962 we believe our knowledge of molecular architecture to be metrical and our techniques for measuring the sizes and shapes of molecules to be well-founded and accurate; giant molecules involved in the processes of life, heredity, and disease are coming under investigation more and more . . . the central theme of molecular structure remains stronger than ever. "Pursuit of the details of molecular structure and molecular environment is the occupation of all chemists part of the time and part of the chemists all of the time" (Wertz, 1955).

This is inevitably so, since, in their simplest expressions, the principal objectives of theoretical chemistry are to relate molecular structures with physical properties on one hand and with reactivities and reaction mechanisms on the other.

"Molecular engineering" becomes possible in proportion as these objectives are attained. By molecular engineering I mean the deliberate planning and construction of molecular species which will, *by design*, form materials in bulk with properties required by some particular situation.

In the past, useful substances have often emerged by chance. Hundreds of examples could be quoted, from Glauber's discovery of the salt bearing his name, through Faraday's isolation of benzene, Perkin's accidental formation of the first coal-tar dyestuff, Kipping's investigations on the organic chemistry of silicon, etc. to Fleming's recognition of penicillin in culture filtrates of *Penicillium notatum*.

The present-day benefits of many materials are by-products unforeseen by earlier workers, whose objectives were in the realm of "pure"

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rather than "applied" science. If Liebig and Dumas between 1831 and 1835 had not been interested in chloroform as a substitution product of methane, it would not have existed for Simpson to use as an anaesthetic in 1848; aspirin and antipyrine were not found because analgesics and febrifuges were being sought; "plastics" and artificial fibres—now so universal—have followed, rather than preceded, academic research on polymers and polymerizations.

Such has been the past. Today, knowledge concerning the dependence of properties on molecular structure and molecular shape is already sufficient to permit the "tailoring" of molecules to suit specified needs. Thus from the readily available molecule cholesterol we know how to make four hormones to control four important but different vital functions, the androgenic, oestrogenic, progestational and adreno-cortical. Starting from 6-aminopenicillanic acid (which occurs in large quantities in fermentation liquors) a series of new and partly synthetic penicillins can be prepared. Several of these are superior to the natural penicillins in having broader antimicrobial actions or reduced side-effects, and in resisting staphylococcal penicillinase, the intervention of which is one of the most serious problems of antibacterial chemotherapy.

The research field in which physiological properties are being related to molecular structure contains many such examples. We know which groups of atoms are likely to produce the effect desired. The sorts of molecules likely to be useful against tuberculosis or dysentery or leprosy or syphilis or malaria, or typhus, or to be efficacious as antiseptics, anaesthetics, hypnotics, anticonvulsants, tranquillisers, diuretics, analgesics, anthelmintics, etc., as well as those potent as fungicides, weedicides and insecticides, can all be forecast with reasonable certainty by the chemist.

Topically we may entertain hopes that virus diseases will shortly receive a setback when the molecular nature of "interferon" becomes better understood. This substance, discovered in 1957 by Isaacs and Lindenmann, is capable of interfering with viruses different from that from which it was isolated. Its molecule has a protein nature. It appears to be non-toxic in effective doses. It could be the starting point of another major breakthrough in chemotherapy, analogous to that following the recognition in 1935 of the bacteriostatic action of "Prontosil".

However, it is when we turn to research fields in which purely physical properties are being related to molecular structure that we find opportunities for molecular engineering to be most numerous and varied. Let me mention only two examples. The connections between colour and constitution have attracted chemists for over eighty years; the "rules" in this classical problem are well established; the atom-groups which carry colour are known; the ways in which they should be put together in a molecule are clear. Today substances with specified colours can indeed be planned on the drawing board. By adding other groups carrying the ability to attach the coloured molecules to fibres, surfaces, etc., dyestuffs are produced. Thirty or so years ago, when fibres not composed only of cotton, silk, or wool began to be used, the dyer encountered new problems which were overcome by the use of *a priori* knowledge. A very recent instance is the dyeing of glass fibres; ordinary organic molecules cannot be chemically bonded to glass, towards which certain silicones, however, are known to have high affinity. By preparing monomeric alkoxy-silane azo dyes under anhydrous conditions, and then polymerizing them with water, polysiloxane azo dyestuffs are produced which retain the affinity for glass and which consequently can be used for dyeing fabrics of this material.

Synthetic fibres and "plastics" offer great opportunities for molecular tailoring or engineering. Surprising materials for old and new purposes have emerged, and will continue to do so, from these families of substances. If you want a lightweight alternative to steel, an isotactic polypropylene fibre will give you a tensile strength of over 70 kg./sq. mm., a high-tensacity Nylon 66 fibre up to *ca.* 80 kg./sq. mm.; epoxy resin adhesives are suitable for the bonding of concrete kerbs to road surfaces or for the joining of broken bones; plastics of all kinds have entered building practice. . . . The sudden withdrawal of macro-molecules developed during the past 25 years would leave many of us toothless and near-naked!

Some of the strongest challenges to molecular architects and engineers must today be foreseen from aviation, the newer vehicles of which are being planned to operate under conditions as yet sometimes explored only theoretically.

Speeds are increasing rapidly. It took 35 years for aeroplanes to reach 400 m.p.h. "First generation" jet airliners (the investment in which by Western nations is estimated at £2×10⁹) fly at 500 m.p.h. Bigger and faster

"second generation" machines will be appearing in a year or two—such as the Convair Coronado 990, the Boeing 727, or the de Havilland Trident, which will cruise at 600 m.p.h. with a hundred or more passengers. France is planning the Super Caravelle to travel at twice the speed of sound, while her Mirage III is described as a Mach 2.2 interceptor. An aerodynamic test vehicle (Jaguar) for speeds of about 7000 m.p.h. was displayed at the last Farnborough Air Show. Operational heights have also risen in 50 years from a few thousand to a hundred thousand feet.

Problems are many. Rates of climb and descent must put stresses of 50 g. or more on materials of construction. Rapid rises of skin temperatures will occur (at 100,000 ft., the skin temperature at Mach 2.5 would char rubber, at Mach 4 would equal that of red-hot iron, above Mach 4.5 would melt aluminium!). Wings, fuselages, etc. therefore should have high melting points, good thermal conductivities, and ability to retain their tensile strengths when hot; moreover, since rates of change of skin temperatures may easily exceed 40° per minute, materials with low thermal expansion coefficients are most desirable. At present, stainless steel is contemplated for the first supersonic aircraft.

Apart from the vehicle itself, the conditions of life must be preserved for crew and passengers. Noise at take-off may be 200 db. (90 db. is equivalent to a pneumatic road-drill at 20'); sound insulating materials must be developed. The ozone content of air even at 20,000' is ten times that at sea level, sealers, windows, etc. must be resistant to this reactive substance; it is poisonous and should be reduced to safe concentrations by any pressurization system. Cosmic and other radiation is greater at high altitudes when the normal screening effect of the atmosphere is absent; external or internal protection must be provided, for "astronauts" at least. If the air in the boundary layers is heated much above 500° C it will begin to ionize and begin to prevent communication to and from the vehicle. Any electrical components working in the ambient atmosphere will suffer the tendency to corona discharges well known at low pressures, with consequent risks of deterioration of insulation, radio interference, and fire; new barriers must be devised. Temperature-resistant transparent window materials (or lens materials, if closed circuit T.V. observation is to be used) will be needed. Engines, instruments, lubricants, fuels—the difficulties are formidable and numerous; they

are all, directly or indirectly, challenges to chemistry.

The extent to which the challenges are topically being taken up is difficult to gauge; in the present international climate much of such work, if successful, would be "secret". From the literature it is clear that a good deal of frantic product-searching is proceeding. Notably, recent demands for polymeric material complying with exacting specifications of resistance to a heat of 500°, to oxidation, and to hydrolysis have encouraged the investigation of inorganic polymers, e.g. those incorporating atoms such as P, N, B, Si, Ti or Sn in their molecular skeletons; Russian chemists have described backbone units of $-Al-O-Al-$ and $-Al-O-Si-$, but details of the products and their applications are not disclosed.

Likewise it is obvious that considerable attention is being given to fuels and propellants. Some of these sound frightening to an ordinary chemist: nitronium perchlorate, hydrocarbons with mixtures of liquid oxygen and fluorine, liquid hydrogen with liquid ozone. . . The chemist's long-range hopes of improving rocket thrust are said to involve free radicals or free atoms. . . physicists say that the specific impulse obtainable with accelerated plasma from exploding wires greatly exceeds that from present chemical systems.

A propos radiation dangers, not only during space flight but generally, it is interesting that during the last few years a number of substances have shown promise as internal protective agents. The most active contain a sulphhydryl group and an amino or guanidino group separated by not more than three carbon atoms, e.g. cysteamine $HS \cdot CH_2CH_2 \cdot NH_2$. They reduce the biological damage from ionizing radiations not only in isolated cells but also in intact animals; they are most effective against X- and gamma-rays and high-energy electrons, less against α -particles. A typical report states, e.g., that 800r of X-rays will kill ten out of ten mice within 15 days but if the mice are given an injection of a good protective agent shortly before irradiation all will be alive several months afterwards. A few experiments with monkeys suggest that primates can be protected. Unfortunately, at present, to obtain a significant degree of protection the doses have to be such as come close to giving pharmacological side-effects. . . nevertheless, the development is encouraging.

Turning to other fields, one of the most exciting challenges to the student of molecular architecture is now being met in the border-

land between chemistry and biology. Since the subject concerns the fundamental processes of heredity, its development holds great potential for future good or evil.

It is well known that hereditary factors are carried in the chromosomes of cell nuclei, and that the chromosomes are replicated during cell division, one set being passed to each daughter cell. Inherited characteristics are associated with definite positions on the chromosomes, arranged in order "like beads on a rosary"; these positions are *genes*.

A gene is no longer thought to be an abstract term for a unit factor of heredity, but rather a definite type of macro-molecule belonging to the deoxyribose nucleic acid (DNA) class; these DNA's between them contain chemically coded genetic information and directions for nearly all living organisms (the only exceptions appear to be certain small viruses, in which the DNA is replaced by the very similar nucleic acids from ribose instead of deoxyribose).

The deoxyribose nucleic acids are condensation polymers derived from nucleotides, units composed of a sugar (deoxyribose) chemically bonded to a base and a phosphate grouping; polynucleotides such as DNA are nucleotides joined through these phosphate groupings.

Examined by the electron microscope and by other physical methods, DNA's appear as fairly straight rod-like macromolecules with lengths of 1000 Å or more and diameters *ca.* 20 Å. One macromolecule may contain 25,000 bases. Early chemical work showed that hydrolysis of DNA's provided only four bases, two purines (guanine and adenine) and two pyrimidines (cytosine and thymine); moreover—and this was surprising—while the proportions of the four bases from DNA'S of different species could vary, the ratios of guanine/cytosine and adenine/thymine were always close to unity. A pairing of bases in the macromolecule was thus indicated.

Gene replication is characterized by its accuracy. This—and other details—is explained by the DNA model proposed by Watson and Crick in 1953. DNA is envisaged as a double helix formed from two polynucleotide chains intertwined. On the outer aspect of the resulting column are the sugar and phosphate units; the bases are inside. The two strands are held together by hydrogen bonds between the purines and pyrimidines of one strand with the appropriately paired pyrimidine and purine respectively of the other.

The genetic message is conveyed by the sequence order in which the nucleotides occur.

The reproduction process is pictured as a partial unwinding of the double helix, then the H-bonding of nucleotides to the bases thus exposed in the single strands, followed by an enzymic "zipping up" of the phosphate residues of the entrant nucleotides to complete a new double helix. The fresh macromolecule is thus formed on the old as on a template; it replicates its predecessor precisely.

Thus in a way the units of heredity are the four bases, guanine, cytosine, adenine and thymine, and the guiding principle during reproduction may be stereo-chemical in that only guanine will pair with cytosine, or adenine with thymine.

Certainly a door is opening; what are the prospects seen through it? Will man be able to manipulate the genes and thus interfere—for good or evil—with the principle of natural selection hitherto operative on the human gene pool? If so, the 1 per cent of congenital abnormalities among births may be avoided. We who have heard Pauling speaking about the sickle cell gene and its association with immunity against juvenile malaria, or on phenylketonuria and its transmission, will realize that a start has already been made in relating unfortunate inheritance to details of molecular structure.

The fundamental role which the nucleic acids appear to play in the processes by which life is continued in a regulated way prompts the question: how did they first originate on this planet?

It is thought that perhaps the crust of the earth formed about 5×10^9 years ago. The early atmosphere was a reducing one in which the atoms in it were attached more to hydrogen than to oxygen; photosynthetic organisms based on carbon dioxide may not have appeared until roughly half a million years ago.

Could chemical evolution have started from methane, hydrogen, water, ammonia, carbon dioxide and perhaps monoxide, under the action of ultraviolet and ionizing radiations from the sun and outer space and/or radioactivity from the rocks of the earth?

The answer from experiment is "yes". Garrison *et al.* (1951) have formed formic acid by irradiating a solution of carbon dioxide in water in the Berkeley cyclotron. Urey and Miller (1955, 1959) have demonstrated the production of acetic, succinic and certain amino-acids by passing an electric discharge through a mixture of methane, ammonia, water and hydrogen. Thus, theoretically, these simple starting materials could lead to polypeptides, proteins, and a host of naturally important

molecules known today. Random synthesis *could* therefore have started the organic chemistry of the earth.

For life to start among such organic compounds, however, it seems that the organizers of protein synthesis and development—the nucleic acids—must be present. Could they—or primitive prebiotic forms of them—have come from astral bodies other than the earth?

Here again the answer appears to be “yes”. Some years ago, spectroscopic examination suggested that fragments such as CH, CN, C₂, etc. are in comets and widespread throughout the Universe, that infra-red bands corresponding to C–H bonds can be seen in the dark regions on Mars (Sinton, 1959) . . . We may hope that, with rocketry, closer inspection of the Moon, Mars and Venus will soon give more precise information. In the meantime, tons of meteorites are annually falling on to the earth, and some of these contain carbon as organic matter extractable by solvents.

Calvin has recently (1959) analysed some of these extracts, using the sensitive and refined techniques available today, and has characterized one of the compounds present as—most probably—cytosine. Here, then, is an important component of DNA of extraterrestrial origin, presumably available from somewhere in the solar system or from outer space. Can this discovery be irrelevant to the fascinating questions concerning the origin of life on earth or elsewhere?

All the matters mentioned so far can be viewed with optimism; their study satisfies the in-built curiosity of man; their applications can be used for the benefit of mankind. They constitute progress. Can such progress continue?

It is submitted that the outlook for science in general, should, today, be one of pessimism. Difficulties are increasing at every turn.

Consider the “training” of young research scientists. They *must* come from the ranks of undergraduates, but these are being crammed into our universities in a way such that their standards of opportunity, of laboratory experience, of study, of staff contact, are being reduced year by year. Who says these standards are sinking? It is the people best qualified to judge, those appointed to spread teaching and research in their particular branches of knowledge . . . not Councils, Senates, Administrations, or Education Departments. *On the evidence before us* these bodies often value quantity before quality. (Students do not protest because they do not know what to

expect from a university; and because the majority wants, at any price, to be stamped with the B.Sc.). Schools are suffering similar troubles.

No political party seems prepared to deal with the problems of education on realistic lines or to risk the unpopularity which might be involved thereby. Equality of opportunity is a noble claim; should not those making it be required to demonstrate better, than at present, their ability to use the opportunities adequately? Watering down matriculation and graduation requirements, like so much else visible in public policies, encourages the increase of the less educable or adaptable persons, and tends to undermine incentive and slacken the will to work. Sir Charles Darwin has remarked that paying attention to the inferior types “is the most inefficient way possible of achieving the perfectibility of the human race”. If in education we could give our best services to the most deserving, the numbers of first-class scientists emerging from our universities would not be reduced, but—having avoided dilution of their opportunities by the mediocre mass—their quality would be improved. (In the Sydney Chemistry School, swollen classes in Years I–III are not producing any growth at all in the IVth Year Honours group.) When a box-office sells more tickets than its theatre has seats, how can everyone have that view of the stage for which he has paid, and which the building was designed to give? The manager, anxious to preserve the standards which he understands is at once in conflict with the directors if they press him to overfill the house. For seats, read laboratory places and facilities, for manager, read Professors and Heads of Science Departments . . . and you will understand one of the reasons why the “training” outlook is gloomy!

The extraordinary—almost exponential—recent growth of science exacerbates the situation. To speak only of chemistry: its ever-growing literature and ever-widening range seems likely to impose a major brake on progress. Under the title “Knowledge Lost is Ignorance Increased”, I gave some facts and figures in 1957. In pure chemistry alone two to three new papers are appearing per hour. Only about half these are in English. A chemist who thinks he will keep abreast of current research by perusing “Chemical Abstracts”, which tries to have world-wide coverage, must read and understand about 46 columns of tersely written small print each day. This would be an extremely arduous task; in practice, an

impossible one. The "information services" of chemistry today are geared above the human and mental powers of chemists. Other scientists make similar complaints about their fields.

Our minds being limited, all we can hope to do is to keep up with some small part of our subject, perhaps only with the literature of our own research fields; over-all knowledge is passing more and more out of our reach. Remembering how often, in the past, advances have followed cross-fertilization between different disciplines (how chemistry has benefited from the ideas and techniques of physics, for example), it seems inevitable that future progress *must* be handicapped. Thus the outlook on all matters touching the recording, distribution, accessibility, digestion and correlation of information is dismal indeed!

Faced with events during the last decade we cannot be blind to the deleterious effects on science of political pressures or—in the future—of a change in social attitudes.

Already, during the last decade we have seen political pressure applied in two of the largest countries of the world: Russia and the U.S.A. In the earlier 1950's basic ideas accepted by most non-Russian geneticists were, within the Soviet Union, declared incompatible with the doctrine of the Communist Party. Chemists will remember how the approaches of Pauling and Ingold to problems of molecular structure were officially condemned as "bourgeois and anti-democratic".

Nor can we forget the well-organized attempt to paralyse independent thought, discussion, dissent, or protest about certain matters in the U.S.A. The national hysteria of the McCarthy period occurred among English-speaking people not dissimilar to us. The fever may now have lost its heat, but it has not entirely gone. According to Margaret Gillett, writing in "Vestis" recently, the American Association of University Professors has reported that during 1959–60 external attempts at "interference, molestation, or penalization" were still coming to academic people from three main areas—government, the courts, and, less formally, public opinion, and the Press. Among various instances she notes dismissals of instructors on racial grounds, or even—as in the case of a Professor of Mathematics at Fisk University—because he invoked the Fifth Amendment and because the authorities feared public opinion.

Prominent and valuable research workers have not escaped. In 1954, Dr. J. R. Oppenheimer was, by a 4:1 vote, denied access to "restricted" data, because he did not have the

continued confidence of the U.S. Government; yet, as is well known, he had taken a distinguished and leading part in the development of the atom bomb at Los Alamos and within the Atomic Energy Commission. Oppenheimer's motives were questioned when he advised against the hydrogen bomb project; he was accused of "lack of enthusiasm". *Nature* made editorial comment at the time that the Oppenheimer enquiry had analogies with the case of Dr. Dreyfus two generations earlier!

I recall these events, not in detraction of the U.S.A. or U.S.S.R., but to illustrate that having occurred elsewhere, or in the recent past, they could recur anywhere now or in the near future. Their hindrance to the advance of science is indisputable; that the motivation behind them was given out as "loyalty" or "patriotism" is also well known.

Of course, a new situation was created by the construction of atomic weapons. Until these appeared the development of weapons depended on the specific application of published facts and principles, largely of physics and chemistry... any new scientific knowledge involved had no revolutionary consequences for the advance of science. Now nuclear research is depending on the expenditure of vast sums of public money (justified at first by war needs). Inevitably, such investigations, born of war-time necessity, have been covered from birth by the secrecy which was anathema to science in the nineteenth century, when no government would have known or worried about what was going on in the research laboratories of a country.

Today, therefore, the advances in one area of science are equated with national security... the old assumption that science has no frontiers is, in reality, untenable.

This secrecy has consequences not dangerous only to the progress of science. It virtually deprives the public of accurate and authentic information without which sound judgment of public policy is impossible. "Democratic government", if it cannot run on knowledge, is liable to do so on prejudice.

The last point bears on the dangers to science from a future change in social attitude. Poorer and poorer education through greater and greater shortages of science teachers in our schools will increasingly produce populations unable to understand the significance of new discoveries in science or to undertake the hard job of thinking for themselves and of honestly and courageously stating and facing their conclusions.

Serious science, unlike science fiction, is not really popular today. (Only 7% of adult education in the U.K. in 1952 was in scientific subjects; in all the Australian universities together, between 1950-59, Arts students have increased their proportion from 27% to 30%, but Science students only from 13.2% to 13.9%, according to the 1960 report of the Australian Universities Commission.)

Governments are not in general controlled by the governed. The basic patterns of human behaviour are much the same today as they were before the external circumstances of life were altered—for a minority of mankind—by the applications of scientific discovery and invention, and before some of the jargon of science entered the vocabularies of daily conversation, and before the superficial appearance was created that we are living in a “scientific age”, when people think and act “scientifically”.

If people really did so act, they could not be easily misled. A. V. Hill has spoken of science thus: “The fundamental principle of scientific work is unbending integrity of thought, following the evidence of fact wherever it may lead, within the limits of experimental error and honest mistake. On this there can be no compromise; and since science is a universal interest of mankind, recognizing no barriers of race, class, religion or opinion (provided that it is honest), a necessary condition of its advance and application is one of friendliness, frankness and equality. Goodwill and integrity, therefore, are indispensable alike to scientific progress itself and its successful employment for the benefit of mankind. Those who look to scientists as magicians, able to conjure a universal formula out of a hat, may be disappointed to find only so ancient a doctrine: and admittedly, there *is* far more to science than integrity and goodwill. But these are the qualities chiefly required to utilize the opportunities, to resolve the problems and difficulties, which science has provided for present-day society”.

Knowledge, understanding, integrity, and goodwill... these qualities together cannot often be seen in governments or governed; the first two alone may have powerful and disastrous results if used by the ruling clique in a totalitarian state. A placid public, accustomed to having its emotions aroused by advertising agencies, can be stimulated to violent fanaticism by propaganda bureaux (as we saw in pre-war Germany). Can we trust the relatively ignorant and uncomprehending

nations of the world to resist attempts to limit or proscribe or even to persecute science and scientists? Politicians take a short view—three or five years—of their policies; if and when catastrophic and uncontrollable changes begin to become apparent to everyone, could not a shallow analysis seem to show science to blame? Scapegoats will then be needed. (We might remember Rome in the third century: the Christians were not understood, they challenged the social and political convictions of the world around them, they refused to do sacrifice to the Emperor. “When political troubles were unusually grave... it was thought prudent to persecute the Christians”—Fisher, pp. 91, 95.)

Will it not be easy to say that although every alleged benefit to mankind has brought also its own dangers, the latter may outweigh the former? As A. V. Hill put it in 1952: “Without our present knowledge of bacteriology and preventive medicine, gigantic armies could never be kept in the field, and land war on the recent scale would be impossible... The indiscriminate use of insecticides, by upsetting the balance of Nature, can quickly do more harm than good. Radio communication may be used for spreading lies and disorder... Developments in microbiology... may be used in the future for biological warfare, with effects at present unpredictable; and control by international agreement and inspection might be very difficult...” He goes on to comment that “Science is not alone in this: liberty may lead to licence, religion can be used to inflame passions, and laws can be exploited to protect wrongdoing...”

We know that all knowledge, not only that of the natural world, can be used for evil as well as good, that bacteriology and medicine are not to be blamed for modern war, nor radio-communication for lies and propaganda; but how will our fellow men react?

To restrict licence, we restrict liberty; to restrict religion we persecute. Already there are sincere and thoughtful non-scientists among us who think that certain lines of research should be banned; such people would probably—from the highest motives—support and justify the limitation or repression of scientific activity... from fear of the consequences of uncontrolled experiment. Science could thus find itself in a universal police state where no scruples would be permitted; and who then would choose the “safe” subjects, and by what authority?

As scientists, we would undoubtedly reject such ideas, continue to act as though the seven

capital sins were not implanted in man, note that good use as well as misuse of knowledge is possible, and leave applications to the value judgments of other people. This way has led to what A. V. Hill has called the ethical dilemma of science. To quote: "The dilemma is this. All the impulses of decent humanity, all the dictates of religion and all the traditions of medicine insist that suffering should be relieved, curable disease cured, preventable disease prevented. The obligation is regarded as unconditional: it is not permitted to argue that the suffering is due to folly, that the children are not wanted, that the patient's family would be happier if he died. All that may be so; but to accept it as a guide to action would lead to a degradation of standards of humanity by which civilization would be permanently and indefinitely poorer. Conduct usually falls short of principles; but that would be the worst reason for abandoning principles altogether.

"In many parts of the world advances in public health, improved sanitation, the avoidance of epidemics, the fighting of insect-borne disease, the lowering of infantile death-rates and a prolongation of the span of life have led to a vast increase of population. Not only is the population increasing, but also in many places its rate of increase is still rising; and these processes will take so long to reverse that for many years to come the shortage of natural resources, particularly of food, is bound to provide increasing deprivation and disturbance."

He then refers specifically to the 1951 "First Five Year Plan" produced by an Indian Government Planning Commission, and says: "A doubling in the past thirty years of the survival-rate (births minus deaths) has led to a rate of increase of nearly $1\frac{1}{2}$ per cent a year, a total of 5 million every year in a population of 360 million.

"With all the effort that the First Five Year Plan will represent, it will be possible barely to restore by 1955-1956 the pre-war standards in regard to food and clothing. Increasing pressure of population on natural resources retards economic progress and limits seriously the rate of extension of social services so essential to civilized existence.

"The pre-war standard, in fact, was very poor; much of the population existed below the level of a decent life, scores of millions only just above that of famine. Yet the gigantic national effort proposed in the Five Year Plan, even if successful, may only just restore that miserable standard. Can it sustain it then if the rate of population increase continues? It is easy to

answer that a higher standard of life has led in other countries to a gradually falling birth-rate; but a higher standard requires a far greater charge on natural resources of all kinds, which cannot be met until the pressure of population is reduced. . . .

"Malaria is admitted . . . to take an annual toll of a million lives, and tuberculosis of half a million. The resolute use of insecticides and anti-malarial drugs could soon reduce the former to a small fraction; tuberculosis is bound to require more effort and a longer term. Nobody would dare to say that steps to combat these diseases, and others such as cholera, to improve rural and industrial health, to increase the supply of drugs and medical equipment and services, should not be taken on the highest priority; but the consequence must be faced that a further increase of a million people a year would result. Thus science, biological, medical, chemical and engineering, applied for motives of decent humanity entirely beyond reproach, with no objectionable secrecy, has led to a problem of the utmost public gravity which will require all the resources of science, humanity and statesmanship for its solution.

"The example of India has been taken because of the sheer magnitude of the problem and because its seriousness is now admitted by humane and responsible men; but the same conditions exist already in many parts of the world and will soon exist elsewhere. It is *not* a question only of food; if a higher standard of life is to become universal, with education, communications, housing, reasonable amenities and public health, a far greater demand will be made on all such natural resources as power, chemicals, minerals, metals, water and wood. One is left wondering how long these can possibly take the strain. . . .

" . . . But education alone would not have been enough, or indeed possible itself, without a substantial measure of material and social betterment; and the expense and effort involved in this would have been infinitely greater than in the application of medicine and hygiene, which after all has been relatively cheap. Had it been possible to foresee the enormous success of this application, would humane people have agreed that it could better have been held back to keep in step with other parallel progress, so that development could be planned and orderly? Some might say yes, taking the purely biological view that if men will breed like rabbits they must be allowed to die like rabbits, until gradually improving education and the demand for a higher standard

of life teach them better. Most people would still say no. But suppose it were certain now that the pressure of increasing population, uncontrolled by disease, would lead not only to wide-spread exhaustion of the soil and of other capital resources but also to continuing and increasing international tension and disorder, making it hard for civilization itself to survive: would the majority of humane and reasonable people then change their minds? If ethical principles deny our right to do evil in order that good may come, are we justified in doing good when the foreseeable consequence is evil?"

This lengthy quotation is from A. V. Hill's Presidential Address to the British Association on September 6th, 1952. It summarizes not so much a dilemma for science as a problem for mankind which, as no other has so imperatively done before, demands international and concerted action.

In bare essentials the problem is not new. More than one and a half centuries ago Malthus, in his "Essay on Population", drew attention to the conflict between the geometrical increase of the human species and the arithmetical increase of areas under agriculture; but Malthus did not foresee food production increasing faster than the population, through the introduction of chemical fertilizers and scientific methods during the nineteenth century, and his threatened consequences did not arrive.

His arguments were reconsidered by C. G. Darwin in 1953 when attempting a projection over "The Next Million Years". Adopting the estimate that man doubles his numbers in a century he will have multiplied by 2^{10} in a millenium or by roughly a million in 2,000 years. If the present population is about 3×10^9 , two millenia hence it will be 30×10^{14} . There are about 52.7 million square miles of land on the earth's surface, i.e. *ca.* 1.63×10^{14} sq. yards. The theoretical population density for A.D. 4000 is thus roughly 18 per sq. yard!

Actually, Darwin's assumed growth-rate is far too small; quadrupling in a century seems nearer the truth. According to the *Demographic Yearbook* for 1957, the net increase from 1955-56 was 47 million persons, close on 130,000 per day . . . at least 1.6% per year. In the thirty years from 1930-1960 the *increase* in the world's population has been three times the world's *total* in the New Testament period, or twice the global total at the time of the Reformation.

The rate of growth continues to accelerate. Even if the rate of growth were constant, the net annual increase would expand (by compound

interest, so to speak) as the base is enlarged; but in fact all evidence shows the rate itself to be rising. The numbers resemble those for the kinetics of a non-stationary chain reaction . . . when the rate becomes infinite, the reaction is over! Likewise, should a population's growth rate become infinite, the population must annihilate itself.

A paper by von Foerster, Mora and Amiot in 1960 has relevance and significance; it concludes that *on presently available data* the human doom-date is A.D. 2026.87 ± 5.50 .

These authors state that "A bibliographical search produced 24 estimates . . . of the world population, ranging over approximately 100 generations from the time of Christ ($t=0$) almost to the present ($t=1958$). These estimates were carefully checked with respect to their independence, and those which were suspected of being merely cross-references in the literature were eliminated from the statistics in order to avoid improper weighting. Then, with "doomsday" written as t_0 , N the population at time t , and $\pi=t_0-t$ (i.e. the time left until doomsday), the data fitted the equation $N=K/\pi^k$ when $K=(1.79 \pm 0.14) \times 10^{11}$, $k=0.990 \pm 0.009$, and $t_0=2026.87 \pm 5.50$; A.D. 2026.87 is the 13th November, 2026 . . . the date when the rate should become infinity!

The authors make this interesting comment regarding the equation just quoted: if Charlemagne had used it "with the evidence he could have had with respect to the world's population, he could have predicted doomsday accurately within 300 years. Elizabeth I of England could have predicted the critical date within 110 years, and Napoleon within 30 years. Today, however, we are in a much better position, since we are required to extrapolate our evidence only 4 per cent beyond our last point of observation: we can predict doomsday within approximately 10 years."

I have reported two extreme treatments of the situation. Both are alarming; the point of the second is that ultimate catastrophe need not be delayed for millenia. Undeniably present statistics warn us as to what lies immediately ahead—that in the next 10 years more than another India (some 450 millions) will be added, largely to the underdeveloped nations of the world.

The U.S.A. and Australia have annual growth rates (neglecting immigration) of 1.7% and 1.4% respectively; Europe shows less than 1%; India, 1.8%; Africa, *ca.* 2%; South America, 2.4%; S.W. Asia, 2.5%. For certain smaller areas the rates are over 3%,

e.g. Costa Rica, 3.9%; the Dominican Republic, 3.4%; Syria and Taiwan, 3.8%; Malaya and Venezuela, 3.1%. (Remember, an annual increase of 3% means a doubling of population within 24 years, and 4% a doubling in 18 years.)

Population, more than any other threatening international crisis, has been apparently ignored by governments. The United Nations cannot be said to have brought it strongly before world attention. Probably world agreement to attempt to control population could never be attained: an aggressor nation or bloc would never permit its people to restrict their numbers.

Hill recalls "asking an eminent Indian who had taken part in drawing up the so-called Bombay Plan of 1944 why there was no mention of the gravest problem of all, overgrowing population; he replied that his colleagues and he had indeed discussed it, but had decided to leave it to God".

Without the intervention of miracles, this means that Man, as a wild animal, will tend to multiply up to the limit of available food supplies; these, despite our increased scientific and technical know-how, cannot keep us today, let alone tomorrow! Subsistence levels, already very low in many of the countries just mentioned, must become lower; larger starving marginal populations will appear. Dangers to peace are obvious. Have not some of the present tensions demographic roots? I think of Indonesia's desires on West New Guinea, of Nasser's efforts to form a United Arab bloc. Is it coincidence that Algeria has a net annual increase of 2.75% and that in the Caribbean region the figure is even higher? Perhaps "tomorrow is already here" in some places!

We must expect present political systems to be altered. Democracy lacks survival value. Darwin comments that the state of parasitism on the community engendered by modern social conditions is impermanent because in the end the parasite destroys its host and then itself perishes: the process is likely to be hastened by the concomitant reduction of the more intelligent, these being driven to have fewer children than the others. The non-parasite containing communities will survive, and those that multiply most will dominate the earth by sheer numbers. Government may be by some "hero" who has sufficient sense to adapt himself to a society of dense population. Intellect may count, but not morality... "in a highly competitive world the sinner has many advantages over the Saint". Conditions of work will be more severe for the less efficient; there will be more discontent and less happiness.

People will look back regretfully on the prodigious stores of energy and other natural resources that have been so lavishly wasted... back to days when human life had a higher value.

Can such a gloomy future be avoided? The answer is simple: only if birth rates are diminished and/or death rates increased. To be effective the numbers involved need—each year—to be *ca.* 50 million. Even in the near future, redistribution by emigration would not suffice (if all the world's shipping were used to take people from China, China's population would still increase; the net immigration to Australia of 97,000 per annum is less than one day's world increase!). Without going into details, no evidence at present suggests that birth-rates can be reduced significantly, or in time to restore population stability (for which an average of 1.43% is required; no country at present shows such a low figure). The "haves" are mostly nations whose population increases occurred hand-in-hand with their industrial revolutions, the "have nots" are being suddenly hit by increases *before* achievement of large-scale economic, social, and technical development. I cannot imagine the "have nots" so rapidly using and improving the accumulated knowledge of the "haves" that they will be able to increase their food and other essentials by geometrical progressions which even equal the progressions by which their populations will grow. A world climax at some stage seems inevitable.

Regretfully, therefore, I conclude that, under natural law, control will occur by deaths... Looking around, the only relevantly applicable power possessed by man, and which he has multiplied geometrically by factors surpassing those of his numerical increase, is his power of killing. Today, the inhabitants of 22 cities of Sydney could be exterminated in a few seconds. Tomorrow Albania might drop an atom bomb on Naples and start the train of events imagined by Neville Shute in "On the Beach"... but I do not think the rest of the story would be quite as he sketched.

I believe that a few million "Adams and Eves" would—with the aids of science—survive the holocaust; but they, more than ever, for revival and reconstruction of a way of life, will need all the knowledge we can leave them.

Our duty is clear: to advance the science of man with that of matter, to look forward, over the vale of tears, to Bertrand Russell's vision of a society where individuals grow freely,

where hate and greed and envy die, where man is great and appreciates what is noble, beautiful, gentle, and wise, where wisdom and reason prevail.

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The Volatile Oils of the Genus *EUCALYPTUS* (Fam. Myrtaceae)

1. Factors Affecting the Problem

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ABSTRACT—Although the essential oil constitution of about half of the known species of *Eucalyptus* (family Myrtaceae) have been investigated, the majority of these cannot be regarded as having been adequately characterized. In addition, such factors as hybridism, the occurrence of chemical variants, and the taxonomic limits of species, all of which are highly significant in determining the essential oil status of *Eucalyptus* species, have not always received sufficient attention. In this paper both the qualitative and quantitative chemical variation within species are examined. Qualitative variation occurs when the components of the oil from one tree do not coincide in identity with those in the oil of another tree, either in the same or a different population of the species. Quantitative chemical variation occurs within a species when oils from different trees have similar qualitative compositions, but show wide fluctuations in percentages of the components.

1. Introduction

Note: the botanical nomenclature used is that of Blakely (1955).

The work of Baker and Smith which commenced in 1890 and spanned a period of 30 years can be regarded as being the starting point of the proper understanding of the *Eucalyptus* oils and their constituents. Their work on the eucalypts was summarized in the monograph ("A Research on the Eucalypts, Especially in Regard to Their Essential Oils") the first edition of which appeared in 1902 and the second edition in 1920. In this second edition the taxonomy and essential oils of no fewer than 177 species and varieties are described.

However, in spite of extensive investigations into the volatile oils of the Australian flora, the eucalypts, which account for the greater portion of the vegetation of the country, and of which every species yields a volatile leaf oil (as well as a bark oil in many cases), have been relatively neglected since Baker and Smith ceased work in 1920. Since that date, the oils of fewer than 40 additional species have been examined, thus bringing the total to only about half the probable number in the genus.

Unfortunately the greater number of these oils cannot be regarded as having been adequately characterized by the positive identification of their chief constituents by derivative formation or other acceptable means.

The work of Baker and Smith, for example, the largest single contribution, consists in general

of little more than records of oil-yields, together with opinions as to general composition judged by odours, physical constants and other analytical determinations on the crude oils, and on the physical constants of three or four fractions obtained by simple distillation at atmospheric pressure. From time to time the formal identification of a component was recorded, but in the majority of cases the information is fragmentary, often doubtful, and sometimes incorrect. For example, many unproven assumptions were made, such as the sesquiterpene fraction of *Eucalyptus* oils consisting always principally of aromadendrene; or if an ester were readily saponified by cold alcoholic potash, it must necessarily be geranyl acetate. More recent work using techniques and knowledge not available to these earlier workers has shown the incompleteness or inaccuracies in much of these data. The cases of the re-examinations of the oils of *E. andrewsii* Maiden (Jones and White, 1928), of *E. microcorys* F. Muell. (Jones and Lahey, 1938), of *E. citriodora* Hook. (McKern and Spies, 1953), and of *E. maculata* Hook. (McKern, Spies and Willis, 1954) may be cited as examples of this.

2. Biological Considerations

In the evaluation of these earlier data, however, the deficiencies of the chemical work are perhaps of less importance than four considerations of biological significance. These are: (1) the genetics and ecology of the population studied, (2) the effect of hybridism,

(3) the occurrence of chemical variants with the species, and (4) taxonomic uncertainties.

(1) The rational approach to a classification of biological entities with a view to defining the experimental material is through a genetically-based population concept. The modern species concept is erected on a consideration of the relation of the sample studied to the population from which it was drawn, and this in turn to other populations, and to genetic, ecological and other factors.

In order to investigate the chemistry of plants, it is advisable to commence by comparing individuals within a restricted and uniform habitat. When similarities or differences within a population have been thus determined, populations may then be compared. At the same time, chemical characters may be considered in relationship to morphological characters, and hence to any taxonomic problems which may be present.

An instance drawn from the earlier work which demonstrates the need for this experimental approach is provided by the data presented by Baker and Smith for *E. haemastoma* Sm., one of the "scribbly gums" in Series XXXIII Psathyroxyla of Blakely (1955), a group of great taxonomic complexity. Although they were aware of morphological variation within this species, and accepted Mueller's varietal status for de Candolle's *E. micrantha*, they attached no chemical significance to the variation, and hence may not have been critical in the collection of their material. Penfold and Morrison (1927a) observed that, on the sandstone country in the vicinity of Sydney, *E. haemastoma* Sm. and *E. micrantha* DC. could be readily differentiated by fruit and leaf characters. Further, they presented evidence to show differences in oil yield and oil composition between the two; and later (1933) showed that, within *E. micrantha* DC., chemical variation occurred. The chemical data recorded by Baker and Smith for "*E. haemastoma*" oils are therefore of restricted value.

In the majority of cases Baker and Smith derived their oils from a foliage sample which may have included material from many trees, and taken from only one or two areas, and give no indication of the range of percentage constituents to be found in oil samples from individuals drawn from different populations. Examination of individual trees of populations from different areas is essential, not only to obtain information on the quantitative variation in constitution, but also to detect the presence of qualitative variants or of hybridism.

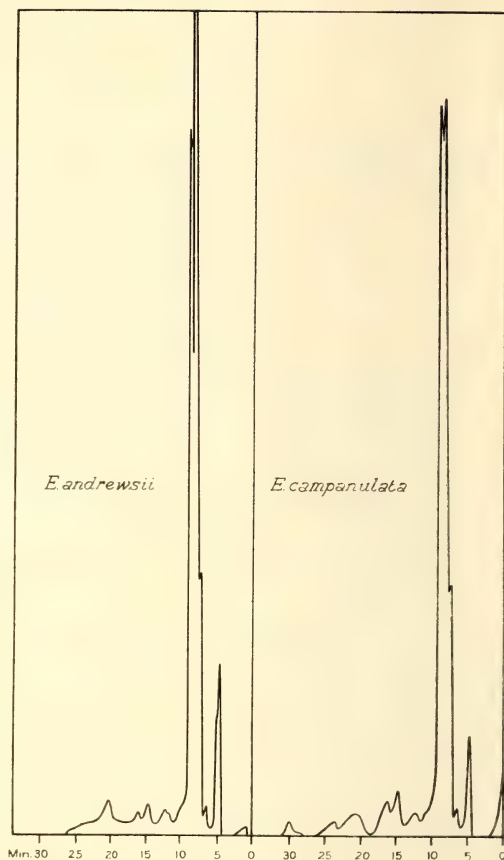


FIG. 1
Chromatograms of crude oils of *E. andrewsii* and *E. campanulata*

The proposed experimental approach should also be of value in the investigation of pairs of species which are regarded as ecotypes. *E. campanulata*, described by Baker and Smith in 1911, is now known to form a continuous population with *E. andrewsii* on the New England plateau of New South Wales. Morphological differences are slight, and grade into each other, and *E. campanulata* is regarded as an ecotype of *E. andrewsii* and represents the eastern portion of the population. Chemical differences may exist, although preliminary data from gas-liquid chromatography indicates that this may not be great (see Fig. 1).

(2) Hybridism, thought by the earlier workers to be unlikely, is now known to be of frequent occurrence between certain *Eucalyptus* species, and many of the oils examined by Baker and Smith were derived from trees of hybrid origin. Pryor (1950, 1951) has shown, for example, that Baker's *E. vitrea* comprises a hybrid of

TABLE I

Oils of Single Trees of Naturally-occurring *E. pauciflora* × *E. dives* Hybrids (" *E. vitrea* ") Compared with Oils from Single Trees of Typical *E. dives* and *E. pauciflora* Growing Nearby

Species	d_{15}^{15}	n_D^{20}	α_D^{20}	Eusemol* %	Piperitone %	Phel- landrene†
" <i>E. vitrea</i> ", tree No. 1 ..	0.9173	1.4879	-11.20°	10	Present**	Present
" " " " 2 ..	0.9249	1.4913	-0.68°	18	"	"
" " " " 3 ..	0.9164	1.4732	-7.04°	3	"	"
" " " " 4 ..	0.9105	1.4862	-15.60°	5	"	"
" " " " 5 ..	0.9323	1.4836	+2.40°	4	"	"
<i>E. dives</i> , single tree ..	0.9074	1.4819	-58.04°	Undetected	44***	"
<i>E. pauciflora</i> , single tree ..	Solid at 15°	1.4997	+18.60°	66	Undetected**	Undetected

* Determined by gas-liquid chromatography.

** Detected by gas-liquid chromatography.

*** Determined by Burgess neutral sulphite method.

† Qualitative nitrosite test, British Pharmacopoeia, 1958.

E. pauciflora Sieb. ex Spreng. with such species as *E. dives* Schau. and *E. radiata* Sieb. ex DC. The oil of *E. vitrea* described by Baker and Smith (1920) is chemically intermediate between *E. pauciflora* and *E. dives* oils, and apparently was derived from a naturally-occurring hybrid between the two species. Data on the oils obtained from naturally-occurring *E. pauciflora* × *E. dives* hybrids (*E. vitrea*) from Hartley Vale, N.S.W., are given in Table I, together with data on *E. dives* and *E. pauciflora* growing nearby.

Mirov (1961) with *Pinus* species, Snegirev (1936) with *Ocimum*, and Gershtein (1951) and Pryor and Bryant (1958) with *Eucalyptus*, have all shown that the essential oils of inter-specific hybrid progeny vary greatly amongst each other, usually showing compositions ranging in between those of the parents. However, the genetic patterns are still not clear, as in some cases it is apparent that recombination of oil constituents does occur, whilst in others certain constituents may be determined in a far-reaching way by one of the parents. Pryor and Bryant (1958), using naturally occurring and manipulated hybrids, have shown that in the cross *E. cinerea* × *E. macarthurii* there is a distinct segregation and recombination of geranyl acetate, whilst the "fluorescent compound" in the *E. maidenii* × *E. rubida* F1 generation seems to be determined solely by the *E. maidenii* parent. Similar results were obtained with percentage yield. More intensive study is necessary, however, before the pattern of inheritance can be determined with any certainty; and it is here that an extensive examination of naturally occurring hybrids would prove valuable.

Other examples of material of hybrid origin upon which Baker and Smith worked are: *E. unialata* Baker and Smith (= *E. globulus* Labill. × *E. viminalis* Labill.), *E. taeniola* R. T. Baker (= *E. sieberiana* F. Muell. × *E. salicifolia* (Sol.) Cav.), *E. marsdeni* C. Hall (= hybrids between *E. micrantha* or *E. haemastoma* and various "Stringybark" species). The compositions of such hybrid oils must necessarily be very variable, and several show oils intermediate between the putative parents.

In addition to these known hybrids, some of the early data for nominally valid species may be suspect owing to the possibility of gene invasion. Certain *Eucalyptus* species are now known to hybridize freely under certain circumstances. Early data for the oil of such spp. as *E. ligustrina* DC., *E. blaxlandii* Maiden et Cambage, *E. moorei* Maiden et Cambage, *E. stricta* Sieb. ex Spreng., *E. wilkinsoniana* R. T. Baker, *E. eugenoides* Sieb. ex Spreng., *E. stellulata* Sieb. ex DC. and *E. viminalis* Labill. must be accepted with a certain caution.

(3) Baker and Smith asserted that the substances synthesized in the plant are constant in nature for a given species. This led them to raise the chemical characteristics of the plant to a status equal to that of the conventional taxonomic features accepted in classical morphology, and they complicated further an already confused nomenclature when they established new *Eucalyptus* species partly or wholly on chemical grounds. So firmly did they propound the theory of the constancy of oil composition for a given species, that when they did encounter marked differences, they had no hesitation in assigning either varietal or specific status to the new form, in spite of the

lack of any clear-cut morphological differences. For example, *E. rostrata* var. *borealis* Baker et Smith, *E. phellandra* Baker et Smith and *E. australiana* Baker et Smith were all founded on purely chemical evidence.

In *Eucalyptus*, Baker and Smith also claimed to have established a relationship between leaf venation and chemical characters. An obtuse "feather" venation was regarded as being indicative of a low yield of oil with pinene as the principal constituent (e.g., *E. gummifera* (Gaertn.) Hochr.). A more acute venation with an intramarginal vein (e.g., *E. globulus* Labill.) was held to indicate a somewhat higher yield of oil with α -pinene and cineole as the main constituents; whilst a reticulate venation was thought to be indicative of a high oil yield with piperitone and phellandrene as the chief constituents, as in *E. dives*. In one case, Baker and Smith went to a great deal of trouble to discover the obscure anastomosing venation of *E. apiculata* Baker et Smith after they had found piperitone in the oil. That such relationships cannot exist became apparent when chemically variant forms were discovered by Penfold and Morrison in 1924 in *E. piperita* Sm.

From their work it is clear that Baker and Smith had encountered several cases of marked dissimilarity in oil constitution within a species. It is interesting to observe their cautious nomenclature introduced in 1902 for a chemical variant of *E. viminalis* which they called Variety "A", in contrast to an extreme case where, in dealing with a variant of *E. dives* (now known as *E. dives* var. "C"), they described the plant purely on chemical grounds as *E. australiana* var. *latifolia*. Similarly, two forms of *E. pauciflora*, one containing α -pinene and the other α -phellandrene as the major oil component, were referred to *E. phlebophylla* F. Muell. and *E. coriacea* A. Cunn. respectively. In some cases the chemical differences are so slight that it is difficult to justify their separations, e.g. *E. gullicki* Baker et Smith from *E. maculosa* R. T. Baker, and *E. nepeanensis* Baker et Smith from *E. bosistoana* F. Muell.

In the year 1924 Penfold and Morrison discarded the theories of Baker and Smith and returned to the conventional species concept based on morphology. In *E. piperita* they found two very distinct forms of the species, one containing an oil with 40–50% of piperitone, and the other an oil low in piperitone but high in phellandrene, eudesmol and cineole, found principally in the more mountainous areas. The latter was tentatively termed the mountain

form or Variety "A" to distinguish it from the typical form which they called the "Type".

Three years later (1927b) these two authors again published data to show that great differences in oil composition could be found amongst individuals within a species population. In this work on *E. dives* it was clearly established that environmental factors were not involved, since the variants, in numerous cases, were found growing side by side in nature. To designate such chemical variants Penfold and Morrison introduced the term "physiological form". By analogy with conventional taxonomic nomenclature, they referred to the form whose oil had been first described as the "Type", the variants being referred to as Variety "A", "B", "C", etc., in order of discovery. The existence of these variants has been established beyond question in such varied genera as *Eucalyptus*, *Melaleuca*, *Leptospermum*, *Backhousia*, *Geijera*, *Euodia*, *Boronia* and *Zieria*, and there seems little doubt that as other genera are examined more examples will be encountered. In Japan the work of Fujita with *Orthodon* and Hirota with *Cinnamomum* has also clearly established the existence of well-defined chemical races within a species.

Chemical variation within plant species is not restricted to volatile oils, but has been observed in phytochemical products of all classes. The investigation of alkaloid-bearing plants has in particular shown this phenomenon (cf. Bick and Todd, 1950; Binns, Halpern, Hughes and Ritchie, 1957).

Chemical variation in a plant population or species appears to be of two kinds, qualitative and quantitative. An example of both kinds of variation in *Eucalyptus* is provided by *E. micrantha* DC. on Fraser Island, Queensland, where the examination of single trees forming part of a continuous population occupying a uniform habitat showed that the oils fell into two categories. One group of oils had limonene, α -pinene and α -terpineol as major components, whilst the other group contained α -phellandrene and piperitone as chief constituents. There thus exists here a clear qualitative difference. However, within the phellandrene-piperitone group, the carbonyl compound varied from 15% to 53% of the oil, thus showing considerable quantitative variation.

Nevertheless, although some species may show great quantitative variation within a given chemical form (see Table II), many instances are known where, within certain areas, a high degree of quantitative stability has been attained, variation in percentage of a given

TABLE II

Examples of Quantitative Variation in Chemical Composition of Leaf Oils of some Eucalyptus Species

Species	Origin	No. of Trees	Oil Constituent Determined	Percentage Range of Constituent
<i>E. radiata</i>	Central Tablelands, N.S.W.	26	Cineole	3 to 60
<i>E. citriodora</i>	Cordalba, Queensland	50	Citronellal	5 to 85
<i>E. lindleyana</i> DC.	Colo River, N.S.W.	28	Piperitone	2 to 50
<i>E. dives</i>	Paddy's River, N.S.W.	4	„	14 to 40

component of the oil fluctuating from plant to plant within narrow limits (see Table III).

In some cases these chemically stable populations are isolated from other occurrences of the species, for example *E. radiata* at Bodalla, whilst in others the population showing quantitative constancy is localized in an area surrounded by populations exhibiting a great degree of quantitative variation, as for example *E. radiata* at Oberon.

Again, *E. sparsifolia* Blakely collected north of the Hawkesbury River between Wilberforce and Howe's Valley yielded oils showing considerable quantitative variation as measured by the eudesmol contents. However, the population south of the Hawkesbury centred about the Dural-Glenorie area yielded oils exhibiting a pronounced degree of quantitative stability. Every tree sampled yielded an oil so rich in eudesmol that it solidified at room temperature, and this character was inherited by their progeny. In Table IV, the eudesmol contents of seven trees selected at random from an open-pollinated progeny from a single tree in the Dural population illustrate this degree of quantitative stability compared with the wide fluctuations likely to be encountered from other areas.

(4) Finally, there are difficulties in interpreting the earlier work on *Eucalyptus* oils owing to nomenclatural confusion. Apart from

the familiar cases of nomenclatural differences arising out of publication priorities and similar considerations, there is the far more serious matter of obscurity of actual identity of experimental material. The taxonomic status of some of the material described by Baker and Smith is now quite uncertain. *E. rydalenensis* Baker and Smith is probably *E. aggregata* Deane and Maiden or an *E. aggregata* hybrid; it is possible that they were influenced by the oil difference from *E. aggregata* to describe this material as coming from a new species. A similar uncertainty is attached to *E. ovalifolia* R. T. Baker which is now regarded as conspecific with *E. polyanthemos*. *E. caerulea* Baker and Smith is a form of *E. caleyi* Maiden, whilst the oil they described under *E. virgata* Sieb. may well be from *E. sieberiana* F. Muell.

It has hence been considered desirable to commence the examination of the oils of *Eucalyptus* species hitherto uninvestigated, and for reasons just discussed, to re-examine the oils of species for which existing data are considered unreliable. Experimental material has been collected from individual trees from as many different localities as possible. Freedom from hybridism in the experimental material has been ensured by collecting in areas where this influence is at a minimum or absent, and also by the examination of the morphology and the oils of the progeny from seed collected from

TABLE III

Examples of Quantitative Constancy in Chemical Composition of Leaf Oils of some Eucalyptus Species

Species	Origin	No. of Trees	Major Constituent	Percentage Range of Major Constituent
<i>E. radiata</i>	.. Oberon, N.S.W.	16	Cineole	63 to 71
„ „	.. Bodalla, N.S.W.	20	„	63 to 72
<i>E. citriodora</i>	.. Castle Hill, N.S.W.*	121	Citronellal	60 to 83
<i>E. dives</i>	.. Sunny Corner, N.S.W.	50	Piperitone	43 to 55
„ „	.. Glen Morrison, N.S.W.	22	„	48 to 54

* Cultivated trees.

TABLE IV
Eudesmol Contents of Oils of *E. sparsifolia*

Wilberforce-Howe's Valley area		Progeny from Dural- Glenorie area	
Tree No.	Per cent Eudesmol*	Tree No.	Per cent Eudesmol*
1	<1	1	74
2	<1	2	84
3	59	3	97
		4	87
		5	95
		6	86
		7	84

* Determined by gas-liquid chromatography

open-pollinated flowers on the experimental trees. Variable populations of uncertain genetic constitution, even if of common occurrence, e.g. the "stringybark" population of the sandstone areas in the vicinity of Sydney, are being temporarily disregarded until more is known of their taxonomic status. A chemical examination of the oils of individuals in such populations, as well as of their progeny, may assist in this investigation.

In Part II, the essential oils of *E. sparsifolia* and *E. mitchelliana* are discussed.

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The Geochemistry of Some Swiss Granites*

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ABSTRACT—The trace-element contents of twenty granites from the Aarmassif, Switzerland, have been determined spectrographically. Results are given for beryllium, gallium, chromium, lithium, nickel, molybdenum, cobalt, copper, vanadium, zirconium, manganese, scandium, yttrium, strontium, lanthanum, lead, silver, barium and rubidium. The samples include early Hercynian granites, which are more or less contaminated by gneissic material, and uncontaminated late Hercynian granites. Trace-element contents of the normal Gasterngranit samples are remarkably constant, and there is a gradual increase in chromium, nickel, cobalt, vanadium and, to a lesser extent, scandium from the Zentraler Aaregranit to the Innertkirchnergranit. The higher contents of these elements in the older granites support the hypothesis of intensive mixing of granitic and metamorphic material in the early Hercynian orogenic cycle. Compared with granites from other countries, the Aarmassif granites tend to be high in lanthanum and yttrium.

Introduction

The Aarmassif is one of the Hercynian massifs of the Alps. It consists of granites, various gneisses and schists, a few small basic intrusions (serpentines) and other rock types. The gneisses and schists are mostly metamorphosed, pre-Hercynian sediments, such as argillaceous and marly shales, and sandstones. Granitic rocks make up 51% of the surface of this autochthonous massif, which is roughly elliptical, being as long as 115 km. and as wide as 25 km. in the central part with a total surface area of about 2000 square km. This paper deals with granitic rocks of the Aarmassif, the locations and details of the samples being shown in Fig. 1 and Table 1.

Geological Background

Full details of the samples, relevant geological information, chemical analyses and petrological data are given by Hügi (1956*a*). Petrological evidence indicates clear differences in age and mineralogical and chemical composition of the Aarmassif granites. Some of these granites are considered to be contaminated by surrounding rocks, i.e. by a pre-Hercynian complex of metamorphics. Two main kinds of granites can be distinguished: (*a*) early Hercynian (Carboniferous) granites which are relatively less acid and more or less contaminated by gneissic material. Examples are the Gastern-

granit, Lauterbrunnergranit, Innertkirchnergranit, Tödigranit, Grimselgranit and Puntegliasgranit; (*b*) late Hercynian (Carboniferous or Permian?) granites which are more acid than (*a*). Examples are the Zentraler Aaregranit and the Mittagfluhgranit.

One of the best examples of a contaminated granite is the Innertkirchnergranit which is largely mixed with biotite-gneisses, amphibolites, etc. During the intrusion of a so-called magmatic solution into the older gneissic substratum, xenoliths of various shapes and sizes (from cubic decimetres to a few cubic metres) were included. Sometimes the line of contact between granitic material and gneiss is clearly defined, but very often no clear contact is visible and only diffuse, poorly-preserved inclusions are present. Recently, good outcrops have been studied in a gallery for a hydro-electric scheme in the Susten-Guttannen area (see Fig. 1).

The earlier granites show more contamination than those formed in the late Hercynian, the contamination increasing from the west towards the east of the massif. The Gasterngranit at the west end has fewer inclusions of country rock (xenoliths) than the Innertkirchnergranit. These trends in contamination are indicated by the contents of some trace elements. The results in Table 2 show the gradual increase in chromium, nickel, cobalt, vanadium and, to a lesser extent, scandium from the Zentraler Aaregranit to the Innertkirchnergranit. The contents of these elements in the pre-Hercynian biotite-gneisses are higher than in an average

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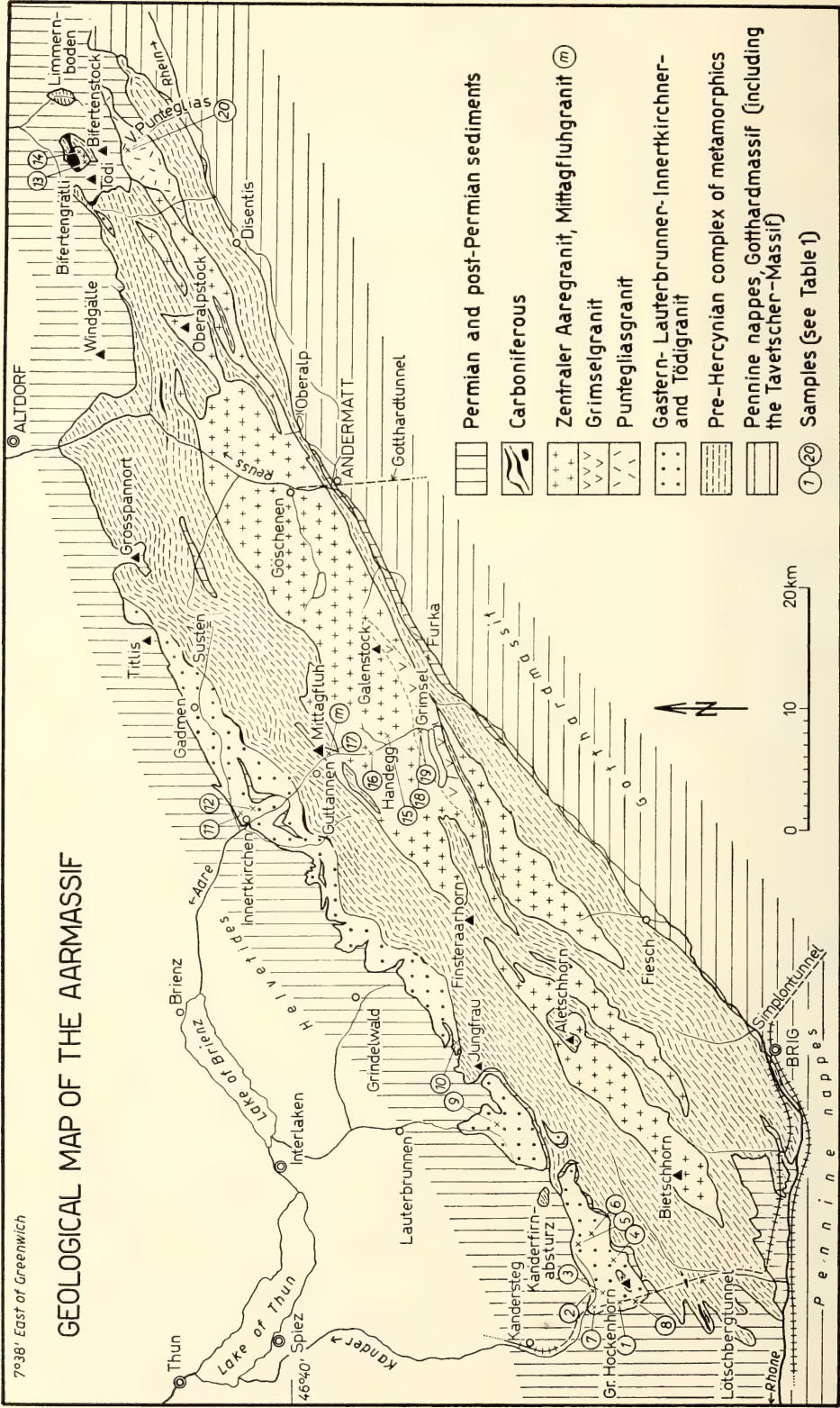


Fig. 1
Map showing locations of samples

TABLE 1
Details of Samples

Number	Type	Location	Ref.
1	Gasterngranit (normal)	Lötschberg tunnel, 7025 m. from north end	2
2	Gasterngranit (normal)	Near Selden, Gasterntal	6023
3	Gasterngranit (normal)	Lötschenpassweg, near Gfällalp	6029
4	Gasterngranit (normal)	Ridge near Sackhorn	6841
5	Gasterngranit (porphyritic)	Kanderfirnabsturz	6156
6	Gasterngranit (with chloritized biotite)	Between Birghorn and Roter Tätsch	6152
7	Gasterngranit (biotite-rich)	Lötschberg tunnel, 4875 m. from north end	1
8	Gasterngranit (muscovite-bearing and porphyritic)	N.E. of the head of the Lötschberggletscher	6019
9	Lauterbrunnergranit (biotite granite)	Rottalaufsteig, south of Lauterbrunnen	264
10	Lauterbrunnergranit (altered by epi-metamorphism)	Jungfraujoch, railway station	6633
11	Innertkirchnergranit (normal ; with zenoliths)	New Susten road, near Innertkirchen	5001
12	Innertkirchnergranit (porphyritic)	Power station, Innertkirchen	5158
13	Tödigranit (coarse-grained, porphyritic ; normal)	Hinterröti firm	36Bi1
14	Tödigranit (granite-porphyry)	N.W. head of the Bifertengletscher	38Bi99
15	Zentraler Aaregranit (normal)	Gelmergasse, near Handegg	3
16	Zentraler Aaregranit (coarse-grained)	Power station, Handegg II	1*
17	Mittagfluhgranit	Near Guttannen	921
18	Grimselgranit (normal)	Sommerloch, on the Grimsel road	504
19	Grimselgranit (decomposed)	Sommerloch, Grimsel power station	4*
20	Puntegliasgranit (normal)	Val Punteglias	38

Note: Numbers in the Reference column refer to page 49 in Hügi (1956a)

granite. These results support the hypothesis that there was intensive mixing of granitic and metamorphic material during the intrusion of the granite in the early Hercynian orogenic cycle. The younger uncontaminated granites (e.g. the Zentraler Aaregranit) have low contents of chromium, nickel, cobalt, vanadium and scandium. In general, these comments are in accord with the ideas of Rankama (1946) on geochemical differentiation in the earth's crust.

Hügi (1956a) has pointed out that the older, contaminated granites of the Aarmassif have relatively high contents of iron, magnesium and calcium, but low contents of silicon and potassium. On the other hand, the younger,

uncontaminated granites are lower in iron, magnesium and calcium, but slightly higher in silicon and potassium, as with the younger granites of the Fennoscandian Shield.

Trace Elements in the Aarmassif Granites

Semi-quantitative spectrographic analyses for trace elements were carried out by a method similar to that described by Mitchell (1948). A mixture of equal parts of the finely-ground rock and carbon powder was filled into a carbon electrode which was the cathode in a 9 ampere d.c. arc. A Hilger Large Quartz Spectrograph (E492) was used and the spectrograms were compared against standard spectrograms, the precision being of the order of ± 30 per cent. Table 3 gives the trace-element contents in parts per million (i.e. g. per metric ton), the elements being arranged in ascending order of ionic radius.

The contents of some elements show very little variation, e.g., gallium 15–25 p.p.m., zirconium 200–500 p.p.m., whereas others vary considerably in different parts of the massif. The average content of molybdenum (< 1 p.p.m.) is in line with the value of 1 p.p.m. found by Kuroda and Sandell (1954) for granitic rocks. Tin was not detected (< 5 p.p.m.), in keeping with the average content of about 3 p.p.m. found by Onishi and Sandell (1957). It is interesting

TABLE 2
*Comparative values for some trace elements
(in parts per million)*

	(a)	(b)	(c)	(d)
Cr	< 1	2–40	40–200	80–100
Ni	3, 5	5–15	20–70	20–40
Co	< 3	5–8	7–25	10–20
V	3, 8	25–150	100–200	100–150
Sc	< 10	< 10 –20	10–20	15

(a) Zentraler Aaregranit

(b) Gasterngranit

(c) Innertkirchnergranit

(d) Biotite-gneiss from the pre-Hercynian complex of metamorphics

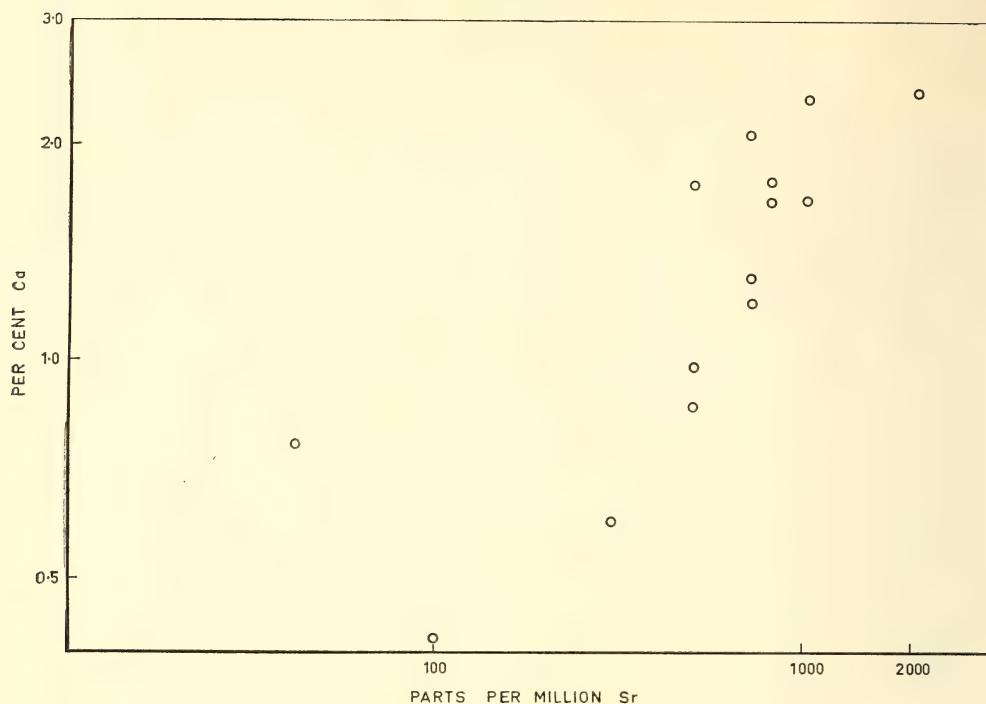


TABLE 4
Contents of trace elements in various granites (in parts per million)

	1	2	3	4
Be	<5- 15 (c. 4)	2-20 (c), 3 (k)	1- 16 (4)	4
Ga	15- 25 (20)	22 (c), 74 (j)	7- 350 (45)	75
Cr	<1- 200 (35)	2 (b), 2-6.8 (j)	<1- 200 (30)	35
Li	15- 300 (170)	40 (g), 180 (l), 460-690 (l)	4- 575 (115)	25
Ni	3- 70 (14)	2.4 (b), 2-8 (j)	1- 70 (8)	2
Co	<3- 25 (7)	8 (b), 0-8 (j)	<1- 25 (4)	0
V	<1- 200 (80)	17 (j)	<1- 280 (50)	2
Zr	200- 500 (300)	460 (f)	74-1500 (270)	900
Sc	<10- 20 (12)	1.3 (c), 0.7 (j)	<1- 20 (4)	<1
Y	40- 200 (100)	5.5 (i)	<1- 400 (50)	40
Sr	30-2000 (600)	120 (f), 90 (h), 90-250 (j)	25-4000 (600)	100
La	60- 200 (120)	43 (b), 60 (i)	1- 500 (70)	35
Pb	10- 30 (13)	30 (e), 9-27 (j), 19 (m)	2- 90 (25)	55
Ba	300->3000 (1800)	630-670 (j)	45-3500 (1300)	900
Rb	200- 700 (500)	520 (a), 830 (d), 170 (g), 455-910 (j)	200-2600 (800)	1500

1. Range and mean value for granites of Aarmassif (this paper).
2. Range or mean values from (a) Ahrens, Pinson and Kearns (1952), (b) Goldschmidt (1937), (c) Goldschmidt (1954), (d) Goldschmidt, Bauer and Witte (1934), (e) Hevesy and Hobbie (1931), (f) Hevesy and Würstlin (1934), (g) Horstman (1957), (h) Noll (1934), (i) Rankama and Sahama (1950), (j) Sahama (1945a), (k) Sandell (1952), (l) Strock (1936), (m) Wedepohl (1956).
3. Range and mean value for granites from Indonesia, Borneo, New Guinea, Finland, Russia, Norway, Germany, Scotland and U.S.A. (references in text).
4. Mixture of 54 Rapakivi granites from various parts of East Fennoscandia (Sahama, 1945b).

In general, average values indicate that chromium, nickel, vanadium, scandium, yttrium, strontium, lanthanum and barium tend to be higher in the Aarmassif samples. However, the results in Table 3 show that the uncontaminated granites (Zentraler Aaregranit and Mittagfluhgranit) have much lower contents of chromium, nickel, vanadium, scandium, strontium and barium, the values being of the same order as those for other granites (Table 4, column 2). Thus, as far as is known, it appears that the Aarmassif granites tend to be high in lanthanum and yttrium. This is probably a regional difference. Gallium, zirconium and lead tend to show similar contents to other granites, except the Rapakivi, which have higher contents. The contents of beryllium and cobalt in granites are fairly constant, although higher values for cobalt were found for the Innertkirchnergranit which is contaminated by gneissic material. In the Aarmassif samples, rubidium tends to be lower than in the Rapakivi granites, while lithium is about the same as in some German samples, but higher than in the Rapakivi. Horstman's values for rubidium and lithium are lower than those reported by most other workers.

Minerals in Fissures

As in other Alpine massifs, the mineralogical and chemical composition of the Aarmassif

granites were changed during Hercynian and Tertiary orogenic activities. There was intense mixing of granitic and gneissic materials, and, in some cases, earlier inclusions of country rock are no longer clearly discernible. Uplift and tectonic movements caused the formation of lenticular fissures which are very common in Alpine granites. These fissures (from a few metres long by a few decimetres wide) may contain well-developed crystals of quartz ("Bergkristall", smoky quartz), adularia, chlorite, calcite, fluorite, sphene and several rare minerals. There is a correlation between minerals present in the fissures formed during the late Tertiary and elements present in the surrounding rocks. The occurrence of some rare minerals can be explained by a higher trace-element content of the granites. Beryllium minerals, e.g., beryl, milarite, bazzite (scandium-beryl), have been found where the parent granites contain about 5 or more p.p.m. Be. In the Aarmassif, milarite was originally found only in Val Giuv, but it is now realized to be a more common mineral in granites of the Aarmassif and of the Gotthardmassif (Hügi, 1956b). The crystals are not usually more than a few millimetres long, but a large crystal from the Grimsel area is 4 cm. long and weighs 12 g., i.e., it contains 0.2 g. beryllium. Many observations indicate that elements in fissure minerals may come partially from a so-called

leached zone around the fissure and partially from farther off. A "pure" leaching theory is no longer valid. During the formation of the Alps, hot solutions (about 200–300°C) rich in silica and carbon dioxide, percolated along fine fissures in the granites. Such solutions became enriched in various elements, leached the neighbourhood of the fissures and helped to form fissure minerals. The formation of the large milarite crystal mentioned above requires all the beryllium from about 50 kg. of Grimsel-granit. Similar considerations apply to other elements such as scandium, molybdenum, lanthanum, yttrium and lead, which are concentrated and fixed in fissure minerals (bazzite, molybdenite, kainosite, fluorite and galena).

Summary

The results for the trace-element contents of the various granites in the Aarmassif indicate that there are increases in chromium, nickel, cobalt, vanadium and scandium from the uncontaminated types (late Hercynian) to the contaminated ones (early Hercynian). These higher contents are explained by the increase in ferromagnesian minerals as a result of the introduction of gneissic material. Samples of normal Gasterngranit from different places and different altitudes show a remarkable constancy in trace-element contents, but a biotite-rich sample has more chromium, nickel, vanadium and scandium, and a muscovite-bearing sample has less of these elements than the normal granites. The higher contents of chromium, nickel, cobalt, vanadium and scandium in the older granites support the hypothesis that there was intensive mixing of granitic and metamorphic material in the early Hercynian orogenic cycle. There are definite trends in the contents of trace elements in the different granites, e.g., the high contents of chromium and vanadium and the higher ratio of nickel to cobalt in the Innertkirchnergranit, and the higher ratio of rubidium to strontium in the Zentraler Aaregranit and the Mittagfluhgranit. The contents of some elements, e.g., gallium (15–25 p.p.m.) and zirconium (200–500 p.p.m.), are remarkably constant throughout the massif.

When the trace-element results are compared with relevant information for granites from other parts of the world, the Aarmassif granites appear to be higher in lanthanum and yttrium. Samples of the contaminated granites (early Hercynian) are also higher in chromium, nickel, vanadium, scandium, strontium and barium.

The occurrence and formation of minerals in fissures are discussed with special reference to the beryllium mineral, milarite.

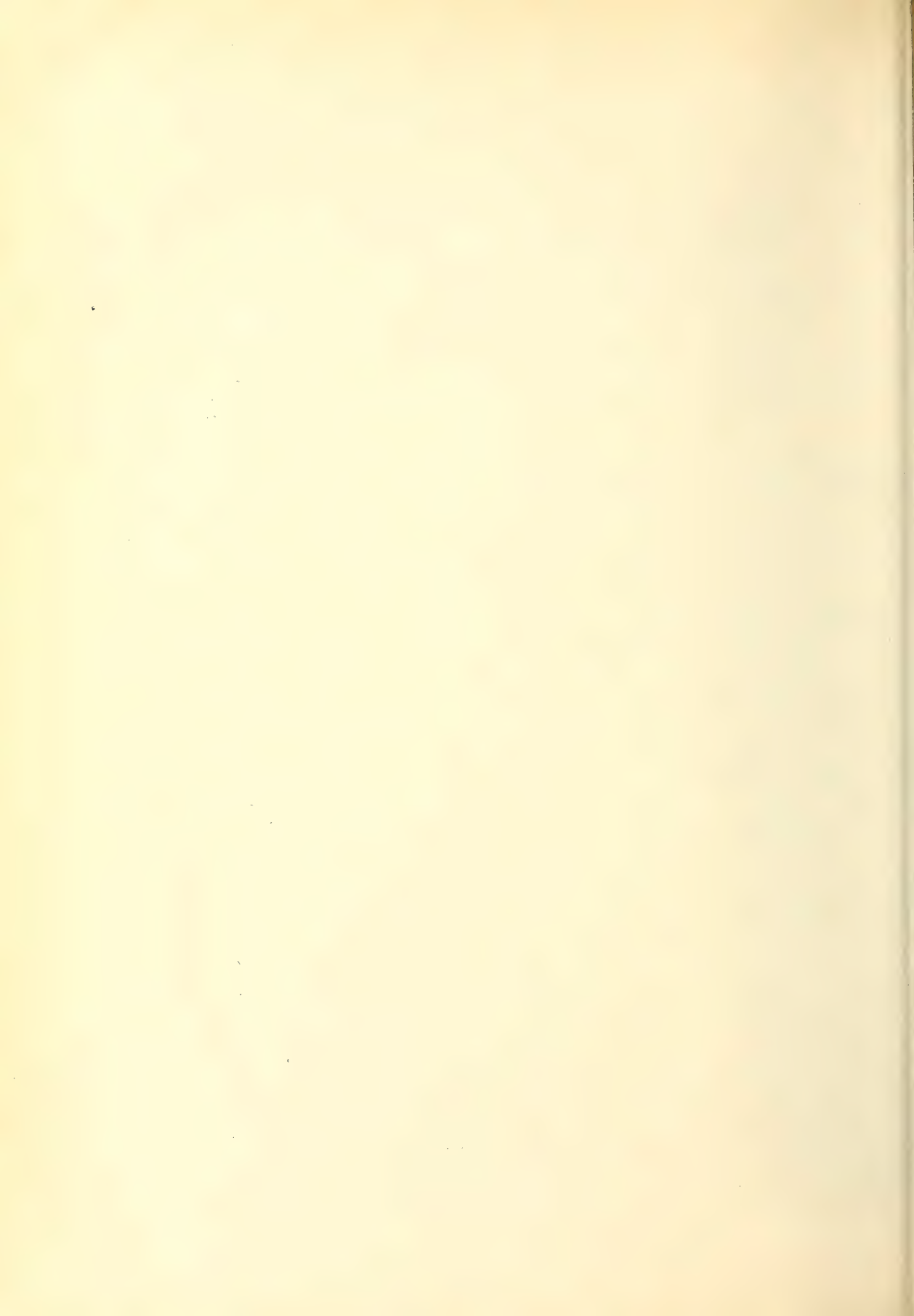
Acknowledgements

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Upper Devonian Stratigraphy and Sedimentation in the Wellington-Molong District, N.S.W.

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ABSTRACT—The Upper Devonian sediments of the Wellington-Molong district are placed in the Catombal Group.

Five formations, the Paling Yard Formation, the Brymedura Sandstone, the Macquarie Park Sandstone, the Kurrool Formation and the Curra Creek Conglomerate, are defined within the Catombal Group. The Paling Yard Formation, Brymedura Sandstone and Macquarie Park Sandstone represent the Black Rock Sub-Group, while the Kurrool Formation and the Curra Creek Conglomerate represent the Canangle Sub-Group. Two geological maps show these formations over fifty miles of strike length from Molong to north of Wellington.

The Catombal Group is preserved in open synclines and anticlines elongated along the strike and often strike-faulted in the region of the limbs of the folds. Detailed petrology of nearly three hundred thin sections shows that the sandstones of the Catombal Group vary from well sorted "clean" orthoquartzites at the base to poorly sorted "dirty" lithic sandstones in the higher formations of the Canangle Sub-Group. Authigenic silica is the main cementing mineral in the rocks of the Black Rock Sub-Group while iron oxide is the most important cement in the rocks of the Canangle Sub-Group. Heavy mineral studies indicate that the sediments of the Catombal Group have a common heavy mineral suite with leucoxene, ilmenite, zircon, garnet, rutile, tourmaline, hornblende and apatite the persistent heavy minerals.

Correlation of rock units is achieved not only from field lithology and palaeontological evidence but also from statistical petrological methods. During the Lower to Middle Devonian a shallow marine basin extended from Wellington to Molong with extensive deposition of limestones, marls, shales and the development of thin localized reefs (the Garra Beds).

Relative uplift of this basin stopped limestone deposition and during the Upper Devonian the rocks of the Catombal Group were deposited. Marine sedimentation in shallow off-shore environments typical of the lower Black Rock Sub-Group formation gradually gave way to the estuarine and terrestrial sediments of the Canangle Sub-Group. In the northern region near Wellington the last preserved phase of sedimentation was a large and extensive alluvial fan system with a thickness of at least 3,000 feet of the red conglomerates, sandstones and siltstones developed from a land mass to the west.

Introduction

This study is an attempt to elucidate the palaeogeography and sedimentation history of the Upper Devonian sediments in central western New South Wales.

A linear belt of these sediments over a hundred miles of strike length outcrops from Cargo to Wellington (Fig. 1).

In order to obtain as much information as possible, detailed studies in thin section petrology and heavy mineralogy were carried out with normal field investigations.

GEOLOGICAL SETTING, TOPOGRAPHY AND STRUCTURAL GEOLOGY

The Upper Devonian sediments in the Molong-Wellington area outcrop over a strike-length of fifty miles and have an average width of five miles (Figs. 13, 14). These sediments are sand-

stones, shales and conglomerates and form a series of rugged hills called the Catombal Range.

The Catombal Range has a high relief one mile west of Wellington at Mount Arthur, which is 900 feet above the alluvial plain of the Macquarie River. The relief increases to the south, and the highest feature, Mount Catombal, occurs in a large isolated syncline to the west of the main range. Mount Catombal is 2,600 feet above sea level and 1,400 feet above older Palaeozoic sediments which outcrop half a mile to the west on the edge of the range.

South of Mount Catombal the relief of the range is more subdued, and in the Larras Lee-Molong region, only a series of low but steep hills remain.

Near Wellington, the sediments of the Catombal Range conformably overlie limestones and marls of the Lower to Middle Devonian

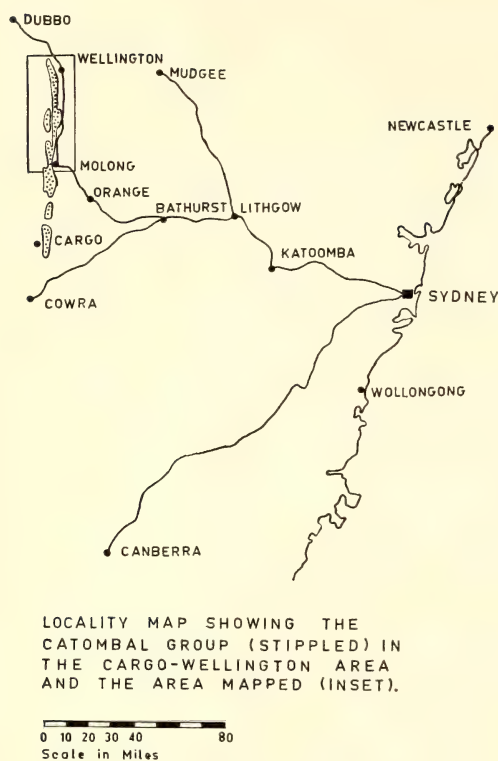


FIG. 1

Garra Beds. To the south, near Molong, there is a slight angular unconformity between the Garra Beds and the Upper Devonian sediments. The Garra Beds thin to the east, and in many regions do not outcrop under the Upper Devonian sediments. In these regions the Upper Devonian sediments unconformably overlie limestones, shales and volcanic rocks previously described by Matheson (1930), Basnett and Colditz (1945), Joplin and others (1952), Adrian (1956) and Strusz (1959). In the Molong region the author has only modified the geological and structural boundaries previously mapped by Adrian (1956) and Walker (personal communication).

The Catombal Range between Wellington and Molong can be divided into three distinct geographical and structural units. The conclusions are mainly based on field evidence obtained during mapping and continual reference should be made to the geological maps (Fig. 13 and Fig. 14). Some of the rock units shown on the geological maps are not defined. Since the relationship of the Upper Devonian to these units is important they have been shown in quotation marks.

1. *A Main Eastern Belt*—This belt originates two miles north of the Macquarie River, west of Wellington, and continues south through Curra Creek, Catombal Creek, Two Mile Creek, Native Dog Creek to where the Bell River first crosses the Upper Devonian, four miles north of Larras Lee (Fig. 13). It measures thirty-seven miles along the strike and has a width that varies from one mile at the northern and southern extremities, to three and a half miles through Curra Creek. To the north this belt is a broad syncline with minor folding in the topmost beds preserved in its centre. South from Curra Creek, the syncline is terminated on the western side by a major fault which persists along this side to the southern boundary at Larras Lee.

On the eastern side of this belt, near Blathery Creek, a synclinal structure, six miles long and an average of three-quarters of a mile wide, is faulted on its western margin where the structure is becoming anticlinal. This structure is the only main divergence that the Catombal Range makes from the eastern margin of this belt.

2. *The Catombal Syncline*—This syncline is fully preserved and lies to the west of the Main Eastern Belt (Fig. 13). The syncline first outcrops about fifteen miles south-south-west from Wellington, and is separated from the Main Eastern Belt by Garra limestones and older Palaeozoic rocks. The length of the syncline is ten miles along the strike, with an average width of two miles, and its eastern margin is only one-half to one and a half miles from the western margin of the Main Eastern Belt.

3. *The Larras Lee-Molong Region*—This region starts about two miles north of Larras Lee and passing south, has an average width of four miles for a distance of thirteen miles to Molong (Fig. 14). The area is characterized by thin, elongated, well preserved synclines and faulted anticlines. Strike faulting and poor outcrops in the valleys help to make this region difficult to interpret both stratigraphically and structurally.

The tectonic style that is characteristic of the Upper Devonian sediments of the Catombal Range is probably closely related to that of other areas of Upper Devonian in western New South Wales. The following points are of greatest interest:

- (a) Most areas of Upper Devonian sediments outcrop as strike ridges and dip slopes. This is essentially due to the highly resistant nature of the rocks deposited during the Upper Devonian.

- (b) Most outcrops of Upper Devonian sediments consist of a series of strike ridges often making a prominent range of rugged hills. Examples of ranges similar to the Catombal Range are the Cocoparra Range near Rankins Springs and the Hervey Range twenty-five miles west of Wellington. Numerous other ranges of Upper Devonian sediments occur further west towards Cobar.
- (c) Open folding is achieved by bedding plane slip in the more resistant and competent formations (conglomerates and sandstones).
- (d) Minor open folding is achieved by failure along closely spaced fracture cleavages in less competent formations (shales and siltstones).
- (e) The folding and the faulting pattern is often controlled by the thickness of individual formations. Where individual formations are thin the folding tends to be more concentrated and faulting more common.
- (f) Individual folds are elongated along a north-south axis and may be several miles long in this direction although only one-tenth or less of that distance in an east-west direction.
- (g) The folds are doubly plunging and often bear a kind of "en echelon" arrangement to adjacent folds.
- (h) Strike faulting is common, particularly on the limbs of steep folds.

MEASUREMENT OF STRATIGRAPHIC SECTIONS

The thickness of individual formations was measured in creek and road sections where good outcrops were available. Measurements of thickness were made with tape and compass traversing along the sections. Enlargements of aerial photos were always used as an aid to field mapping. Measurements that were over one thousand feet were considered to be accurate to within fifty feet. Fairly large errors in accuracy would be caused by localized areas of minor folding and faulting that were hidden by alluvium.

SAMPLING PROCEDURE

Over four hundred rock and fossil samples were collected from measured creek and road sections, although many traverses were also made along the strike. Sandstones were sampled in preference to siltstones because when studied in thin section they could provide more detail than the finer sediments. Representative collections of pebble types from conglomerates were also made.

Previous Investigations

Sussmilch in 1911 completed the first satisfactory compilation of geological information and suggested the geological history of the State. He included the area of Devonian rocks that he had previously described from Spring Creek (Sussmilch, 1907) in the Upper Devonian or Lambian Stage.

This was based on the recognition of a fauna described by De Koninck (1877) containing two species, *Cyrtospirifer disjunctus* and *Camarotoechia pleurodon*, which was found in both the Lambian province and at Spring Creek, and considered characteristic of the Upper Devonian.

In 1922 Benson described the Lambie faunal province and considered it to be definitely of Upper Devonian age.

The first geological map of regional importance in the Wellington district was published by A. J. Matheson in 1930. Matheson describes the "Catombal Series" as beds that contain *Lepidodendron australe* and overlie the *Spirifer disjunctus* horizon or "Transition Stage". Matheson suggested that the "Transition Stage" may be Lower or Middle Devonian, and that the "Catombal Series" may be Upper Devonian.

Joplin and Culey (1938) published a report showing the geological structure and stratigraphy of the Molong-Manildra district; however they did not distinguish the Upper Devonian in the Molong region from that of the "Lambie Stage" occurring near Bathurst, whereas Matheson had noted that there existed a different type of deposition in the Wellington area.

From 1939 to 1945 E. M. Basnett and M. J. Colditz worked in an area of about 500 square miles around Wellington and summarized their work in several important papers.

A considerable amount of fossil collecting was carried out by Basnett and Colditz during their field work in the Wellington district, and these collections, together with those collected by Dr. G. A. Joplin, Miss Alma Culey and Dr. Dorothy Hill, were described by Hill and Jones in a series of three papers from 1940 to 1943. The palaeontological evidence from these papers suggested a Lower to Middle Devonian age for the limestones called the Garra Beds flanking the Upper Devonian sediments of the Catombal Range in the Wellington district.

Stevens (1947) mapped considerable areas of Upper Devonian sediments in the Cargo region south of Molong. He suggested that the sediments at the top, which contained plant

fossils resembling *Rhacopteris*, may extend into Lower Carboniferous.

Joplin and others (1952) compiled a map of the area between Wellington and Canowindra, in which the Upper Devonian sediments are called the "Catombal Formation".

Stevens (1955) presented a map of the Upper Devonian sediments in the Cargo region and named the upmost red measures containing the *Rhacopteris* plant remains, the Canangle Formation, and kept this formation in the Lower Carboniferous.

In 1956, D. B. Walker commenced an investigation of the Upper Devonian sediments of the Cargo region in an attempt to present a sounder interpretation of the Upper Devonian history, basing his work on detailed petrology and stratigraphy. Walker's succession for the Upper Devonian in the Cargo region was:

CATOMBAL GROUP:

Canangle Sub-Group:

Waree Creek Shale
Carlton Conglomerate.

Black Rock Sub-Group:

Columbine Sandstone
Paling Yard Formation.

These formations were defined as follows:

The Paling Yard Formation—Lenticularly bedded conglomerates, red friable sandstones and red and green shales. This formation was normally 200 to 800 feet thick and was characteristic of a basal formation although the conglomerates were not extensively developed.

Columbine Sandstone—A massively bedded formation with extensive development of fine protoquartzites and orthoquartzites with shales characteristically present at the top.

Carlton Conglomerate—Thick bedded, dark coloured, coarse conglomerate, the pebbles being mainly of orthoquartzite and protoquartzite. Thickness variation 20 to 200 feet. Plant remains of *Archaeopteris* sp. and *Lepidodendron australe* occur in interbedded green shales.

Waree Creek Shale—Green shales and siltstones, with plant remains and red conglomerates similar to those in the Carlton Conglomerate. Average thickness 300 to 750 feet.

Walker also completed mapping the Upper Devonian sediments as they outcrop north of the Cargo region towards Molong (Walker, 1958, personal communication). In this more northerly area the composition of the Catombal Group

remained essentially the same, the succession at Molong being:

Canangle Sub-Group:

(No subdivision.)

Black Rock Sub-Group:

Columbine sandstone
Brymedura sandstone
Paling Yard Formation.

The subdivision of the Canangle Sub-Group into the Carlton Conglomerate and the Waree Creek Shale was not possible here although the topmost sediments remained essentially the same; red conglomerates, red shales, red sandstones and the characteristic plant bearing green shales.

In the Black Rock Sub-Group, the Paling Yard Formation and Columbine Sandstone remained at the base and the top respectively; however, another rock unit, the Brymedura Sandstone, was intercalated. The Brymedura Sandstone is 150 to 400 feet thick and consists of coarse current bedded red and white sandstones. This sandstone is an easily mapped unit south of Molong, where it stands out on air photos as thickly wooded ridges.

Stratigraphical Nomenclature

Walker (1958) first suggested the name proposed by Joplin (1952), "Catombal Formation", be changed to the Catombal Group, and he maintained that this could be further subdivided into two Sub-Groups:

1. The Canangle Sub-Group
2. The Black Rock Sub-Group.

In the Cargo region the Canangle Sub-Group could be split into two formations, the Carlton Conglomerate and the Waree Creek Shale, but further to the north in the Molong area it was impossible to divide the Sub-Group into two such formations and it was mapped as a Sub-Group only.

The Black Rock Sub-Group could be subdivided into two formations in the Cargo region: (1) the Paling Yard Formation, and (2) the Columbine Sandstone, while further to the north, in the vicinity of Molong, a third formation, the Brymedura Sandstone, appears above the Paling Yard Formation and below the Columbine Sandstone.

The same lithology that appears in these two Sub-Groups was found to continue in the Catombal Range north of Molong to Wellington. At Wellington, the writer proposes to keep the Group name, "Catombal Group", as the lithology in the Cargo-Molong-Wellington strip

remains essentially the same, and it is also possible to delineate two separate lithological units that correspond to the Black Rock Sub-Group and to the Canangle Sub-Group.

The name "Catombal" originates from the Catombal Range, in the Wellington district, while the names "Canangle" and "Black Rock" originated from localities in the Cargo region and were first named by Stevens (1955).

The proposed stratigraphical nomenclature for the sediments of the Catombal Range in the Wellington-Molong district is as follows:

	WELLINGTON DISTRICT	MOLONG DISTRICT
CATOMBAL GROUP	CANANGLE SUB-GROUP	Curra Creek Conglomerate Kurrool Formation
	BLACK ROCK SUB-GROUP	Macquarie Park Sandstone Brymedura Sandstone
		Canangle Sub-Group Macquarie Park Sandstone Brymedura Sandstone Paling Yard Formation

The term "Macquarie Park Sandstone" is preferred to "Columbine Sandstone" mainly because the type section of the Columbine Sandstone lies outside the area studied and has not been published.

THE BLACK ROCK SUB-GROUP

The Paling Yard Formation

The Paling Yard Formation was described by Walker (1958) as the basal formation of the Upper Devonian in the Cargo region. The Paling Yard Formation in the Molong region is also the base of the Upper Devonian succession; however, its thickness is more often inferred than seen and because of this lack of outcrop has not been described in detail.

Thicknesses of the Paling Yard Formation shown on the geological maps and stratigraphical columns are normally inferred by measurement of the distance between the topmost Garra Bed limestones and the base of the Brymedura Sandstone.

The Paling Yard Formation one mile west of Molong consists of fine buff to green shales and siltstones with occasional very fine pebbly or conglomerate layers.

In the Cargo region the conglomerate lenses in the Paling Yard Formation were quite thick (10 to 15 feet) (Walker, 1958) and contained pebbles of underlying Garra Bed limestones and shales.

In the Molong area the Paling Yard Formation is much thinner with fewer or no conglomerate lenses. The Brymedura Sandstone seems to have taken the place of the coarse conglomerate lenses that outcrop in the Paling Yard Formation near Cargo.

The green and buff shales and siltstones of the topmost Garra Bed shales are very similar to the Paling Yard shales in the Molong area. This similarity in lithology is probably due to the fact that the Garra Beds and the Catombal Group become conformable just west of Molong, whereas to the south of Molong a slight unconformity existed between the two units.

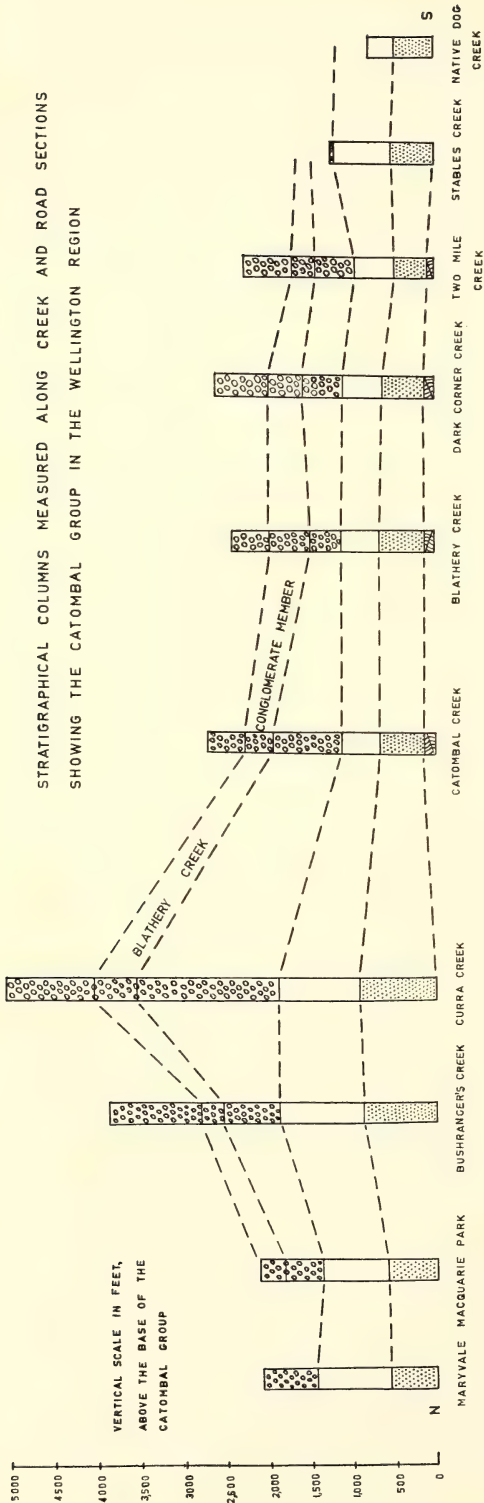
Further to the north the Brymedura Sandstone and then the Macquarie Park Sandstone are the basal formations of the Catombal Group.

The Brymedura Sandstone

STRATIGRAPHY

The Brymedura Sandstone has been mapped to the south of Molong by Walker in 1958 (personal communication). The writer has mapped the Brymedura Sandstone north from Molong accepting the boundaries mapped by Walker to the south of Molong. The type section for the formation was taken in the vicinity of the Brymedura trig. station, two miles south-west of Molong.

The thickness of the Brymedura Sandstone in this locality is 480 feet. It is conformably underlain by the shales and fine siltstones of the Paling Yard Formation and conformably overlain by the protoquartzites and orthoquartzites of the Macquarie Park Sandstone. The Brymedura Sandstone has a remarkably uniform lithology in the type locality and throughout its entire outcrop. It is essentially a coarse grained sandstone with an average grain size of 0.5 mm. It is also well current-bedded, and these current-bedded units are normally two to four feet in thickness. Larger pebbly layers often occur and very rarely beds of finer sandstone are interbedded with the coarser layers. The colour varies from red to white but a red colour is predominant. It forms very prominent outcrops and dominates the topography of the Larras Lee-Molong region, where it stands out above the other formations, forming prominent strike ridges and dip slopes. Variations in thickness in the Brymedura Sandstone have been noted from Molong, north to Larras Lee, and then further north in the region of Two Mile Creek and the Catombal Syncline (Fig. 2). In this northern



STRATIGRAPHY OF THE CATOMBAL GROUP IN THE LARRAS LEE — MOLONG REGION
(COLUMNS MEASURED ALONG SECTION LINES, SEE GEOLOGICAL MAP OF THE LARRAS LEE —
MOLONG REGION)

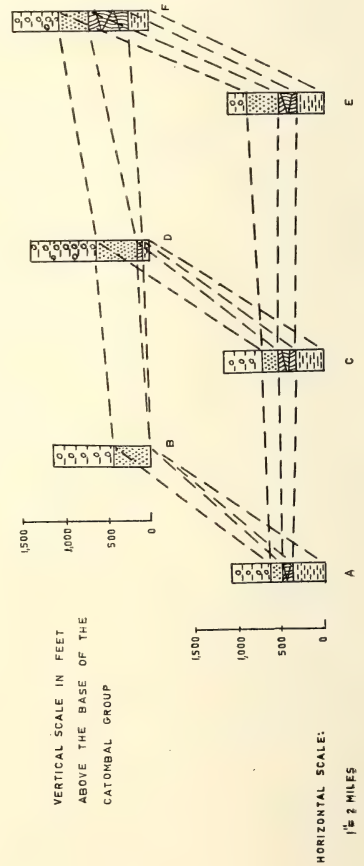


Fig. 2

region the Brymedura Sandstone is overlain by protoquartzites and orthoquartzites of the Macquarie Park Sandstone.

The Brymedura Sandstone outcrops in two areas :

(1) A northern outcrop area which takes in the southern end of the Catombal Syncline and passes over to the east to Two Mile Creek, whence it can be traced northwards to a point just north of Blathery Creek. From this locality the sandstone exists in small isolated patches amongst the Macquarie Park Sandstone north to Curra Creek. There is not much variation in thickness in this northern area and from the southern limit at Two Mile Creek, where the thickness is only 40 feet, to Blathery Creek, where it is 130 feet, and then north of Blathery Creek it is only developed as sporadic lenses, five to ten feet thick.

(2) A southern outcrop area, including the Larras Lee-Molong area and the southern extension of this area mapped by Walker, where it attains a maximum thickness of 810 feet four miles south-west of Molong. North from here the Brymedura Sandstone thins steadily to a thickness of 140 feet at the Gap, west of Larras Lee. On the eastern side of the Larras Lee-Molong region, the Brymedura Sandstone thins very rapidly from a thickness of 480 feet near Molong to 80 feet only five miles further north, and is missing completely in the Larras Lee section.

CURRENT BEDDING

The Brymedura Sandstone is characterized by current bedding. The style of current bedding changes from place to place, but is normally of large units, two to three feet thick, with the preservation of bottomset beds and foreset beds. The top parts of the current bedded units are always sharply truncated along a straight line, the truncation often having quite an angular contact with the previous line of truncation. This type of current bedding has been called "diagonal cross bedding" or "diagonal inclined bedding" (Pettijohn, 1949). When the preserved inclined beds are curved they are called either concave or convex current bedding, depending on whether they are concave or convex towards the younger layers. This type of current bedding is also common in the Brymedura Sandstone, particularly in the smaller units of one to two feet in thickness. Large-scale current bedding in the form of continuous banks of inclined strata are rare but occur in a few localities. At the Gap,

Larras Lee, such a unit attains a maximum thickness of ten feet and has a visible outcrop of some hundreds of feet. In general, the style of current bedding fluctuates between the "diagonal-inclined" and concave types. This seems to depend wholly on whether the curved part of the bottomset beds is preserved. When they are preserved a concave cross bedding results, but when current conditions are stronger the formation of flat bottomset beds seems to be favoured.

Grain size was found to vary with the nature of the current bedding. Thick coarse current bedded units have a higher average grain size than the thinner concave cross bedded units. In many cases, layers of coarser grain size, up to five to ten millimetres in diameter, were preserved in bands at the base of a current bedded unit along the line of truncation of the previous unit. In thick diagonal cross bedded units lines of pebbles were often laid down at sporadic intervals through the units. It seems likely that this type of variation in grain size is due to the way in which coarser layers could be deposited in the current bedded slopes at times when the currents were stronger.

The fluctuation in grain size within such a current bedded unit suggests that the current conditions on the sea bottom were changing rapidly and had some kind of a periodicity. These types of currents would be expected to exist close to the shoreline, where very local variations would be effective enough to produce grain size variation in coarse sand banks.

About fifty measurements made in the Molong-Larras Lee area show a southerly to south-westerly origin for the currents producing the current bedded units. It is believed that although this is below the number needed to make the results statistically reliable, the measurements provide some indication that the currents that deposited the Brymedura Sandstone originated from the south or south-west.

PETROLOGY

Grain size distributions of the Brymedura Sandstone were studied by two methods :

- (a) Friable samples of sandstone were gently crushed with a pestle and mortar and sieved on a standard Ro-Tap machine for ten minutes using a 100-200 gramme sample. W. S. Tyler standard screens were used (Table I).
- (b) Many samples of Brymedura Sandstone were too hard to crush mechanically without breaking across grains, and size analysis of

TABLE I

Statistical Parameters of Eight Sieved Samples of Brymedura Sandstone

Sample No.	Median (mm)	Coefficient of Sorting	Skewness	Kurtosis
085(a)	0.50	1.6	0.96	0.23
085(b)	0.53	1.6	0.96	0.22
084(a)	0.70	1.56	0.82	0.23
084(b)	0.81	1.53	0.94	0.25
058	0.46	1.42	0.99	0.29
148(a)	0.51	1.21	0.84	0.17
148(b)	0.50	1.43	0.67	0.24
235(a)	0.55	1.33	1.34	0.23

Statistical Parameters from Thin Section Size Analysis of Brymedura Sandstone

Sample No.	Median (mm)	Coefficient of Sorting	Skewness	Kurtosis
172(a)	0.49	1.41	0.86	0.17
172(b)	0.53	1.43	0.75	0.22
171(a)	0.64	1.52	0.70	0.23
173(a)	0.65	1.49	0.98	0.17
173(b)	0.53	1.45	0.98	0.24
173(c)	0.55	1.41	0.95	0.24

these samples was studied by measuring grains in prepared thin sections. In this procedure traverses were made across the thin section and the maximum diameter measured. The minimum diameter at right angles to this maximum diameter was also measured and grain sizes were calculated by taking the mean of the two measurements for each grain (Table I).

These results show that the Brymedura Sandstone is a fairly well sorted sand with an average coefficient of sorting of 1.45. Stetson (Pettijohn, 1949, p. 24) points out that most recent near shore marine sediments of sand grade have a coefficient of sorting of 1.45.

Roundness of grains was calculated by comparing grain outlines with standard roundness charts (Pettijohn, 1949, p. 52).

(1) *Quartz*—Most quartz grains were rounded to well rounded (Plate I, 1), particularly the larger grains, which are more easily abraded than smaller ones. Estimates of roundness from all sampled sections showed little variation.

(2) *Rock Fragments*—The rock fragments present in these sandstones tend to be extremely well rounded, particularly soft shaly fragments and saccharoidal lava fragments (Plate I, 1).

PETROGRAPHIC ANALYSIS

A point counter analysis was made of 41 selected thin sections representative of 23 localities over 45 miles of strike length. The point counter was set at a spacing of 0.3 mm and six channels were available for counting and 500 counts were made for each thin section. Chayes (1956) states that the confidence limits for 500 counts are $\pm 3\%$ for 95% of the analyses.

The following six components were counted:

Quartz: including all quartz types except quartz of obvious metamorphic origin.

Metamorphic quartz: quartz fragments made up of a fine mosaic or small quartz grains often with undulose extinction.

Volcanic rock fragments and felspar: including acid and intermediate lavas, tuffaceous sandstones and felspar.

Sedimentary rock fragments.

Matrix: fine silt size quartz, clay, and iron oxide cements.

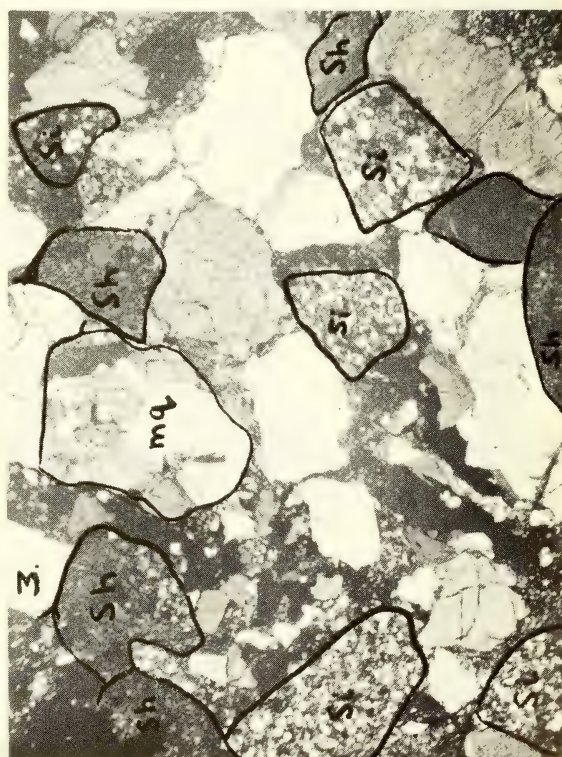
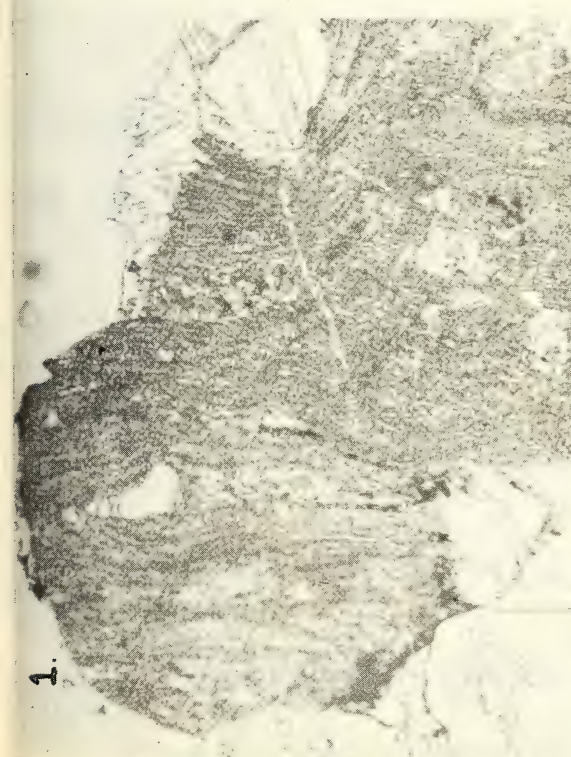
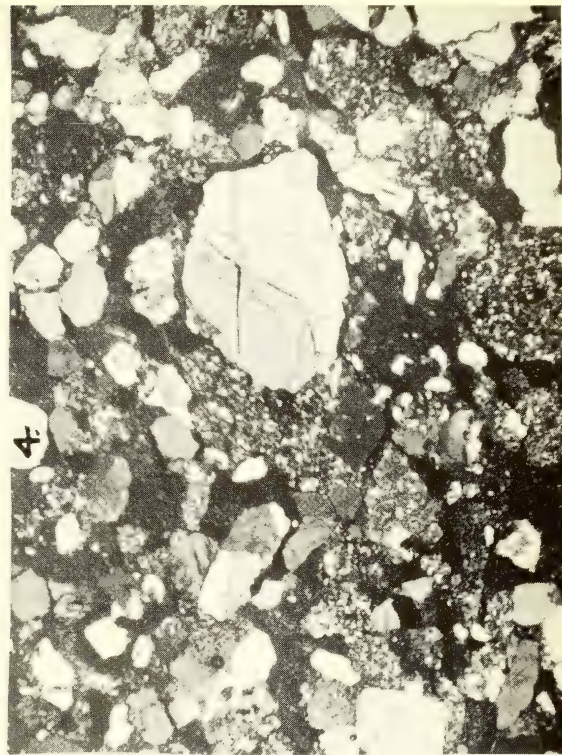
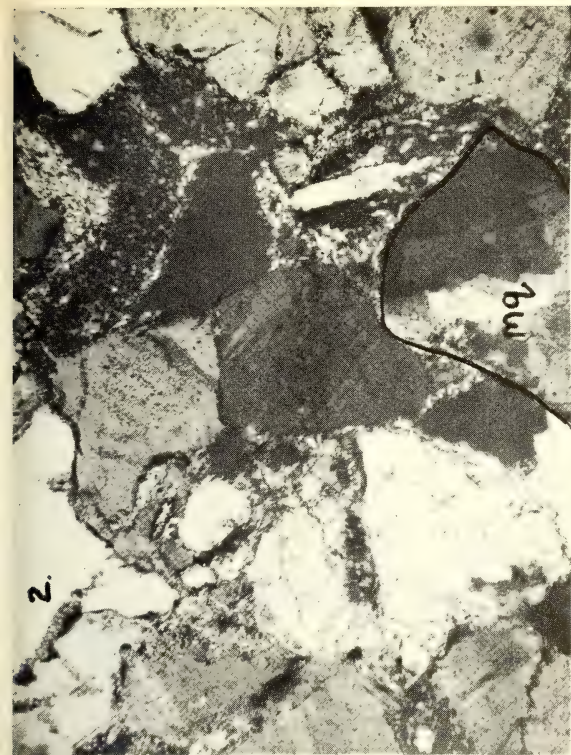
Secondary quartz: all authigenic quartz outgrowths and pore-fillings.

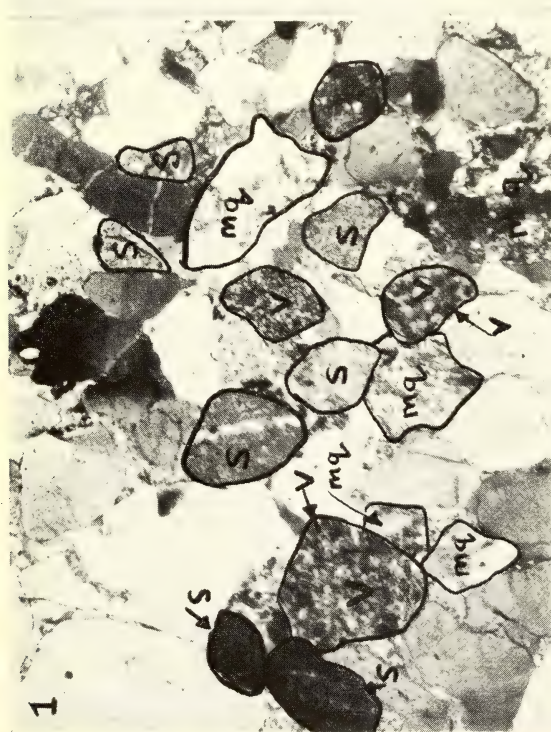
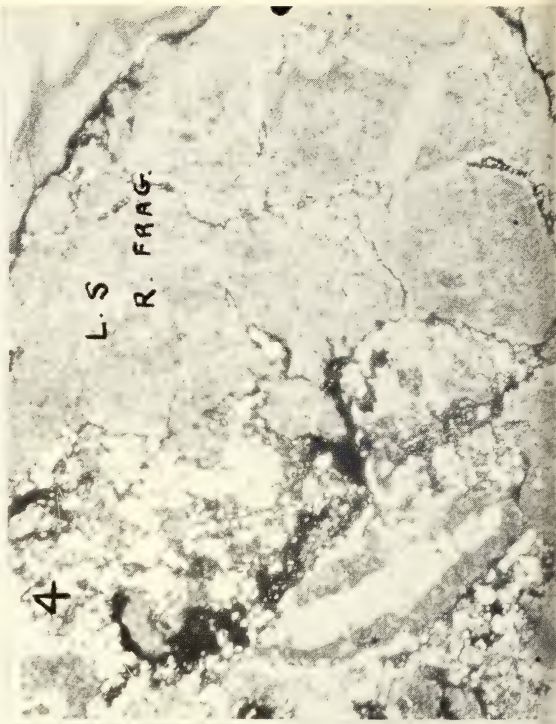
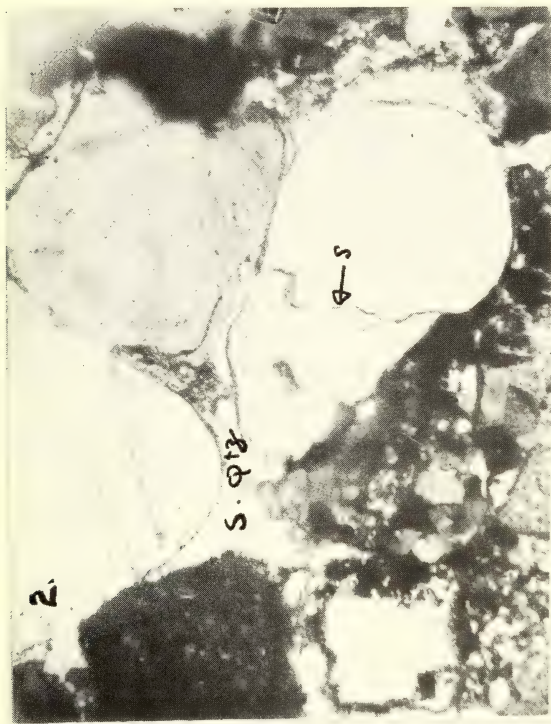
Since the Brymedura Sandstone was characteristically a coarse current bedded sandstone, a mineralogical composition study was made by plotting point counter results on a modification of the triangular diagram proposed by Packham (1954) for the arkose-quartzose suite of sandstones (Fig. 3). Secondary quartz which was present as a cement filling available pore space was not included in the plotted mineralogical composition. Several varieties of detrital quartz have been recognized from thin sections of Brymedura Sandstone.

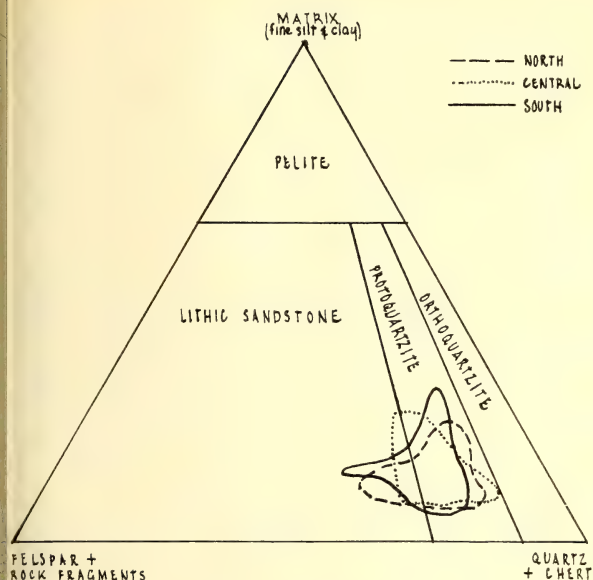
1. *Quartz of ultimate plutonic or granitic origin*: These quartz grains are strain free with planes of liquid and gaseous inclusions, and with larger cavities or vacuoles. They often have smooth curved borders and tend towards an equant shape. Inclusions of zircon have been found in several grains. They are the commonest constituent of the detrital quartz fraction.

2. *Metamorphic quartz*: These grains show either extreme strain shadows or consist of a mosaic of interlocking crystals. They often have an elongate shape and are usually extremely well rounded. Quartz derived from a metamorphic terrain makes up one to five per cent of the detrital quartz fraction (Plates II, 3, III, 1 and 3).

3. *Volcanic quartz*: This type of quartz often has inclusions of lava rock fragments and well-developed embayments. The volcanic quartz







TRIANGULAR DIAGRAM SHOWING VARIATION IN COMPOSITION OF BRYMEDURA SANDSTONES FROM NORTH, CENTRAL, AND SOUTHERN SAMPLED AREAS OF THE CATOMBAL RANGE, WELLINGTON TO MOLONG

FIG. 3

is extremely hard to distinguish from other quartz types, for although it tends to be clear with few bubble trains or inclusions, only three or four grains can be positively identified from some thin sections, while in most thin sections no grains can be identified.

4. *Sedimentary or reworked quartz grains*: These grains show a primary detrital grain which has been rounded, secondarily enlarged and then rounded again, indicating erosion from a pre-existing sediment in which secondary enlargement has occurred. They are often composite grains, in which two or three quartz grains have been cemented by secondary quartz, rounded and then enlarged again by overgrowth. They are not very common, but it is probable that many of the quartz grains of primary igneous origin are actually second cycle grains, but do not show recognizable dusty boundaries that would indicate a previous secondary enlargement.

The rock fragments could be subdivided into two distinct groups: a sedimentary group and a volcanic group.

The sedimentary group has several distinctive types that persist in all sampled sections:

(a) *Dark siliceous shale fragments*: These fragments are black to brown in hand specimen

and are extremely hard. In thin section they consist of very fine siliceous material with illitic clay minerals of the same size. They are often traversed by veins filled with a fine-grained mosaic of vein quartz and this feature is diagnostic for the fragments (Plate III, 1). The veins suggest that the original rock was well consolidated and had been subjected to folding or to some process that caused it to fracture in many places. These fractures must have been closely spaced for one in every three has a vein mosaic of quartz crossing it.

An X-ray analysis of several of these fragments gave the following results: quartz, 75% approx.; illite, 25% approx.; hematite, trace.

(b) *Siltstone rock fragments*: These fragments are abundant, although not as abundant as the dark shale fragments. They vary in grain size from a fine sand to a fine siltstone although most seem to be of medium to coarse siltstone size. They consist of small angular detrital quartz grains with very few other components except clay matrix and iron oxide cement. They often show bands of iron oxide, but these bands may not always coincide with original bedding planes (Plate III, 1).

(c) *Reworked sandstone rock fragments*: This type of rock fragment is rare but has been noted particularly when two or three detrital quartz particles are cemented together, rounded then cemented again (Plate II, 3).

(d) *Clay shale rock fragments*: These fragments are very soft and very well rounded. Their composition consists of an abundance of clay mineral, mainly sericitic illite with a little chlorite. Quartz percentages in these fragments are low and always less than 50% (Plate III, 1, II, 3).

The volcanic group has one distinctive type but many other different types have been described. The distinctive member of this group is an acid saccharoidal lava. These fragments are brown to dark brown and consist of a mosaic of interlocking quartz grains of fine sand to coarse siltstone size with a very small percentage of orthoclase (Plate III, 1).

The mosaic is peppered with anhydrous iron oxide. Under the microscope fragments of this type often show a good "rhyolitic" flow structure (Plate II, 1). About one in every ten fragments shows this banding. X-ray analysis of these fragments gave the following results: quartz, 85% (approx.); illite, 15% (approx.); kaolinite, trace; hematite, trace.

Other types of volcanic rock fragments have been observed, including badly weathered

andesitic and tuffaceous rock fragments consisting of relic feldspar laths, idiomorphic and angular quartz grains and often incorporating other badly weathered igneous rock fragments of the same nature; however, these grains are very rare, one or two grains only recognized in any one thin section.

The mineralogy of the Brymedura Sandstone determined from petrographic analysis of thin sections (Fig. 3) shows that almost all sandstones plot on the protoquartzite field on the triangular diagram.

Detrital quartz varies from 55% to 80%, rock fragments from 10% to 35%, while matrix varies from 5% to 30%. The average composition of the sandstones is 67% quartz, 18% rock fragments and 15% matrix.

No great variation could be found in the quartz percentages although there is a suggestion that to the north in the vicinity of Curra Creek and Catombal Creek, where the Brymedura is known to diminish in thickness, the quartz percentage tends to be higher and hence the sandstones are more mature.

All thin sections have a certain percentage of volcanic rock fragments, mostly acid type, and all but a few thin sections have more sedimentary rock fragments than volcanic rock fragments; however, there seems to be a definite increase in the percentage of volcanic rock fragments towards the south. This would be the case if the volcanic detritus was derived from the south, for with the increase in transport more and more volcanic fragments would be weathered away, and there would be a corresponding drop in percentage volcanic fragments towards the north.

Hence, petrographic analysis shows that the Brymedura Sandstone is essentially of the same composition over the sampled strike length, although it tends to mature to the north with a corresponding decrease in matrix and unstable rock fragments, and an increase in detrital quartz.

The Macquarie Park Sandstone

The Macquarie Park Sandstone is a succession of white and red orthoquartzites, protoquartzites and lithic sandstones with a lesser proportion of white and red siltstones, and occasional shaly bands. It forms the basal formation of the Catombal Group in the northern part of the Catombal Range, where the Brymedura Sandstone is missing. To the south it conformably overlies the Brymedura Sandstone.

Walker (1958) has mapped a similar formation, the Columbine Sandstone, in the Cargo region.

The writer feels that the Macquarie Park Sandstone is essentially of a slightly different lithology from the Columbine Sandstone, with more siltstones and lithic sandstones. Since the two formations outcrop in geographically distinct areas (although along the same north-south trend) it seems more reasonable to keep them separate till further detailed work between Molong and Cargo is carried out.

The Macquarie Park Sandstone is typically of a marine facies at the base, with preservation of species of *Cyrtospirifer* and *Camarotoechia* within the first 300 feet of sediments. The basal sandstones of the formation are characteristically white and spotted with rock fragments. Towards the middle and top of the formation, intercalation of red siltstones and sandstones becomes more frequent.

The top of the Macquarie Park Sandstone is defined on lithology alone, and the boundary is arbitrarily defined where there is a dominance of red siltstones and sandstones over white sandstones and siltstones and necessarily corresponds with the base of the Kurrool Formation.

The type section for the Macquarie Park Sandstone was measured across the western limb of the main synclinal structure of the Catombal Range, north of Wellington, where the Macquarie River crosses the range. The formation was called after the station property "Macquarie Park", where the type section was measured. The type stratigraphic section was:

Top:	
Fine red and white protoquartzites with ? <i>Bothriolepis</i> sp.	115'
White protoquartzites with red siltstones . .	50'
Massive white and red protoquartzites and lithic sandstones	190'
Coarse white protoquartzites and lithic sand- stones with species of <i>Cyrtospirifer</i> and <i>Camarotoechia</i>	35'
White protoquartzites and orthoquartzites . .	50'
White protoquartzites, lithic sandstones and red and white siltstones	120'
White protoquartzites and lithic sandstones	80'
Green and buff shales and siltstones with preservation of <i>Lepidodendron australe</i> . .	20'
Base:	
Total thickness	660'

In this region, the lower sandstones of the Macquarie Park Sandstone rest conformably on massive limestones belonging to the Garra Beds. These limestones contain massive Tabulate and Rugose corals and their age has not yet been determined although a general range from Lower to Middle Devonian has been given to the Garra Beds by Hill and Jones (1940) and Hill (1942).

A study in the variation of lithology and thickness of the Macquarie Park Sandstone was made by measuring stratigraphic sections along main creeks and roads, from Maryvale in the north to Molong in the south (Fig. 2).

The Macquarie Park Sandstone does not vary much in thickness along a north-south line. The formation is thin to the north at Maryvale, where it is 520 feet thick, thickens to a maximum recorded thickness of 920 feet at Curra Creek, and from there thins gradually southward to 460 feet at Native Dog Creek.

The formation appears to rest conformably on the marls, shales and limestones of the Garra Beds from Maryvale south to Catombal Creek, where it rests conformably on Brymedura Sandstone.

In the northern area from Maryvale to Bush-ranger's Creek calcareous sandstones are intercalated with limey siltstones and sometimes with the normal protoquartzite lithology. At Bush-ranger's Creek on the western side of the Catombal Range, the junction between the lowermost protoquartzites of the Macquarie Park Sandstone and the fossiliferous limestones of the Garra Beds is transitional. About 100 feet of sediments in this area represent a transition stage between true limestone and true sandstone lithology with preservation of sandstone, limestone, calcareous sandstone and sandy limestone. This transition between the two different lithologies has only been found in this locality. Unfortunately, outcrops along the side of the range in the area of the limestone-sandstone break in lithology are often extremely poor and covered with alluvium.

South of Two Mile Creek, the Brymedura Sandstone is missing from the succession and the Macquarie Park Sandstone rests unconformably on the "Bell Volcanics". The unconformity could be recognized on the eastern side of the Catombal Range, but nothing is known of the relation on the western side, for the Catombal Group is terminated by the Curra Fault on this side.

A considerable thickening can be seen in the Macquarie Park Sandstone towards the west. A thickness of 450 feet was measured at Blathery Creek. Two miles to the west of the eastern limb of the Catombal Syncline the thickness was 1,600 feet, and further to the west on the western limb of the Catombal Syncline the thickness was 1,800 feet.

The Macquarie Park Sandstone rests conformably on the Brymedura Sandstone in the region of the southern nose of the Catombal

Syncline; however, the Brymedura Sandstone lenses out quickly to the north, where the Macquarie Park Sandstone rests conformably on shales and limestones of the Garra Beds. The Garra Beds thin considerably to the east and are only preserved in isolated lenses underneath the Macquarie Park Sandstone on the eastern side of the Catombal Syncline, while further to the east they are missing.

Six sections were measured in the Larras Lee-Molong region, three on the western side of the area of outcrop and three on the eastern (Fig. 2). On the eastern side the thickness decreases slightly from 480 feet at Larras Lee to 350 feet at Molong. On the western side the Macquarie Park Sandstone is only 150 feet thick in the north but thickens to 350 feet to the south near Molong.

The bedding in the Macquarie Park Sandstone tends to be even with very few cut and fill structures, but with gradual thinning and thickening of individual units. Current bedding is common in the coarser sandstones of this formation but is not the dominant sedimentary structure as it is for the Brymedura Sandstone. The current bedded units vary greatly in size from micro-current bedding (which may be of a few inches wide and several inches along the direction of transport) to macro-current bedding, usually from three feet to tens of feet long.

Lenticular bedding is very common among the coarser grained sandstones, although small tabular units also occurred. Micro-current bedding generally occurred in very fine sandstones or coarse siltstones and consisted of curved wedge-shaped units produced by very gentle scour and fill action. Ripple marks are the characteristic sedimentary structure of the Macquarie Park Sandstone. They are best seen in thinly bedded slabs of fine grained sandstones or siltstones and are particularly well preserved in many creek sections. Some writers (Shrock, 1948, pp. 92-123; Potter and Glass, 1958, p. 19) describe three main types of ripple marks: (1) asymmetrical or current ripple marks; (2) symmetrical or oscillation ripple marks; (3) interference ripple marks.

All three types of ripple marks were found, but asymmetrical and interference ripple marks were the most common. Most asymmetrical ripple marks were produced by aqueous currents. These marks had ridges that were close together in proportion to their height above troughs (Shrock, 1948, p. 93). The ripple marks often constituted a system of parallel ridges, but in many cases they exhibited a fan arrangement in

which the current directions radiated from the centre of the fan.

Most Macquarie Park sandstones are extremely hard, and for this reason only a few samples could be used for size analysis study by sieving. The sorting coefficient tends to be lower (1.34–1.49) than that found for the Brymedura Sandstone, indicating a higher degree of sorting than is present in the Brymedura Sandstone; values for skewness vary considerably, and in many cases this is just a reflection of the variation in clay matrix. Sandstones with low clay matrix tend to have a more perfect size distribution, and hence a near perfect skewness. Sandstones with a high clay matrix percentage have a large amount of material in the fine admixtures and usually have a skewness greater than one.

Study of the size distribution of the finer and more common sandstones was accomplished by measuring grains in prepared thin sections. By comparison with prepared thin sections made from the four sieved samples, it was concluded that a maximum degree of sorting was reached in a sandstone that had a median grain size of about 0.2 mm. and that sandstones of greater or less median grain size had a slightly poorer sorting.

PETROLOGY

The petrology of the Macquarie Park Sandstone was studied in detail from over 100 thin sections; however, although sandstones were the dominant lithology, siltstones were almost as common and there were many shaly horizons. Since sandstones offer a better medium for study more emphasis was placed on these than on the finer sediments.

Detrital quartz of ultimate igneous origin, free of strain shadows, with occasional gaseous or liquid inclusions made up almost 90% of all detrital quartz. Quartz of metamorphic origin was the next most common variety but was not as abundant as it was in the Brymedura Sandstone. No quartz of obvious volcanic origin was noted in this formation although it was present in the Brymedura Sandstone. Volcanic rock fragments persist, however, and it would be expected that volcanic quartz would be present. This may be because embayed quartz grains are hard to recognize when they reach a certain size range, with the embayed sections being broken away with increase in transport and decrease in grain size. Studies in roundness of clastic quartz particles were limited by increase in interpenetration of grain contacts. Many sandstones have lost their original

detrital boundaries because of extreme suturing of adjacent grain borders (Plate I, 2). In samples with little suturing and more secondary enlargement the original grain outlines could be easily discerned and the following results were found:

Most samples of lower Macquarie Park Sandstone contained well rounded to sub-rounded quartz.

Samples taken from higher in the formation, particularly the red sandstones, had quartz grains that were definitely of a more angular nature, being subrounded to subangular.

The detrital quartz in the fine grained sandstones is more angular. When the grain size approached that of a coarse siltstone (0.06 mm.) detrital quartz was always angular to subangular.

The increase in angularity of detrital quartz with increase in stratigraphical height within the Macquarie Park Sandstone implies that the detritus suffered less transport with increase in time. This transition from rounded clastic quartz also coincides with the increase in intercalation of red sandstones and siltstones towards the top of the Macquarie Park Sandstone. With this increase in intercalation of red sandstones and siltstones the "average" size of detrital quartz will become less because of a greater proportion of silt size quartz. The effect of an increase in finer sediments towards the top of the formation will necessarily mean a decrease in roundness. This factor is probably the most important factor controlling the decrease in roundness of clastic quartz from the top to the bottom of the Macquarie Park Sandstone.

Detrital feldspar is an extremely rare component of Macquarie Park Sandstones, particularly along the main eastern belt of the Catombal Range. However, feldspar is an important constituent of Macquarie Park Sandstone within the region of the Catombal Syncline. Several samples on the eastern limb of the Catombal Syncline have small amounts of potash feldspar and occasionally plagioclase. The total percentage of feldspar in these sandstones is always less than one. On the western limb of the Catombal Syncline, many sandstones have quite a high percentage of feldspar (one to 20). Plagioclase seems to be more abundant than potash feldspar. Both feldspars are often badly weathered, and in some slides clusters of kaolinite completely clouded the original grain. No authigenic feldspar was recognized. The increase in detrital feldspar from east to west

across the Catombal Syncline also coincides with an increase in the total thickness of the Macquarie Park Sandstone from east to west.

The rock fragments that occurred in the Macquarie Park sandstones were essentially the same as those that were found in the coarser Brymedura Sandstones. Two groups could be distinguished: a volcanic group, and a sedimentary group.

There is no essential difference in the mineralogy of the sandstones of the Macquarie Park and Brymedura Sandstones (Figs. 3 and 4). The distinction between the two formations is one of grain size distribution only. The Brymedura Sandstone is a coarse grained unit with little variation in texture, while the Macquarie Park Sandstone consists mainly of finer grained sandstones, siltstones and some shales.

The spotted appearance that is so characteristic of the Macquarie Park Sandstones is due to occurrence of brown rock fragments amongst the detrital quartz. Weathered andesitic and toscanitic rock fragments that could be recognized in some Brymedura Sandstones could not be recognized in Macquarie Park Sandstones. Once again the smaller grain size of the Macquarie Park Sandstone would make it hard to recognize such composite rock fragments.

The lower sandstone members of the Macquarie Park Sandstone appear to be much richer in volcanic rock fragments than the upper sandstones. Sedimentary rock fragments are more predominant in the upper sandstones than in the lower. It is possible that changes in source rock composition could be mainly responsible for the progressive change in rock fragment composition; however, it may only be due to the gradual change in the environment of deposition, i.e. from marine conditions with extensive washing and rounding of quartz and hence diminution in soft shale fragments, to estuarine conditions with less washing and reworking of grains enabling the softer shale fragments to persist.

THE CANANGLE SUB-GROUP

The Kurrool Formation

The Kurrool Formation conformably overlies the Macquarie Park Sandstone, conformably underlies the Curra Creek Conglomerate, and is a transitional formation between them. The lithology of the base of the Kurrool Formation is similar to that of Macquarie Park Sandstone, while the lithology of the top of the formation is similar to that of the Curra Creek Con-

glomerate. The junction between the Kurrool Formation and the Macquarie Park Sandstone occurs where red siltstones and sandstones dominate the white siltstones and sandstones of the Macquarie Park Sandstone. The top of the Kurrool Formation is also the base of the Curra Creek Conglomerate, being the first prominent conglomerate (two to ten feet thick) developed in the Canangle Sub-Group.

The type section for the Kurrool Formation was measured in the vicinity of Blathery Creek, 12 miles south of Wellington on the station property of "Kurrool". The Kurrool Formation was 450 feet thick in this section and the type succession measured from the top was:

Red siltstones and red lithic sandstones	100'
Red protoquartzites and lithic sandstones with some red siltstones	50'
Red siltstones and red protoquartzites with some white protoquartzites	180'
Red and white protoquartzites, lithic sandstones and red siltstones..	120'

The Kurrool Formation is thickest in the northern part of the Catombal Range, where it attains a maximum thickness of 1,000 feet at Bushranger's Creek (Fig. 2). From Bushranger's Creek the formation thins towards the south, and from Stables Creek to Larras Lee the topmost beds are missing due to the displacement caused by the fault on the western boundary of the Catombal Range.

The poor exposures and lack of persistent horizons in the Larras Lee-Molong region make it impossible to subdivide the Canangle Sub-Group into separate formations with any degree of accuracy. The lithology of the Kurrool Formation persists southward from Native Dog Creek into the Larras Lee-Molong region, where the boundary between the top of the Macquarie Park Sandstone and the base of the Canangle Sub-Group is still a transitional boundary between red and white sediments. Although many very small (up to one foot in thickness) conglomerate lenses are developed throughout the Canangle Sub-Group, there is a more frequent occurrence of calcareous arenites and rudites and there is an absence of the great thicknesses of massive red conglomerates with large quartzite pebbles which are typical of the Curra Creek Conglomerate farther north.

Strike faulting, minor folding, and erosion make it impossible to judge the thickness of the Canangle Sub-Group in the Larras Lee-Molong region, but the writer considers that at least 1,000 feet of sediments representing this Sub-Group outcrop throughout the area.

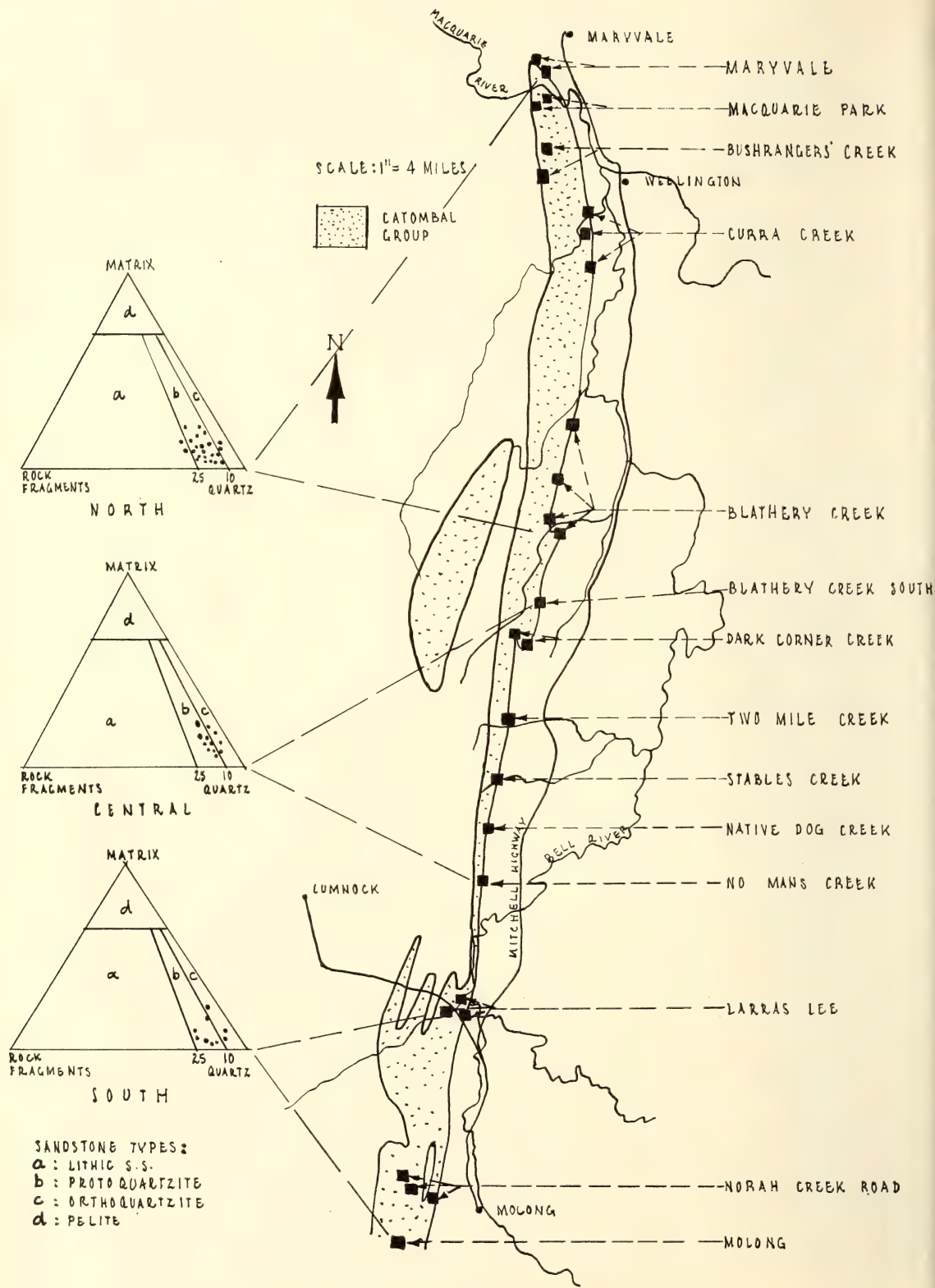


FIG. 4

Map showing sampled localities for thin sections of Macquarie Park Sandstone ; with triangular diagrams showing the composition of the sandstones after grouping into three broad regions, North, Central and South

Grain Size	SANDSTONES > 0.06 mm	SILTSTONES < 0.06 mm
Detrital quartz	Mostly strain free and irregular in shape. A small percentage (1) of the polycrystalline variety that has suffered folding or recrystallization was detected in most thin sections	The fine grain size made it difficult to recognize separate varieties with any degree of certainty although strain free quartz was the dominant type
Roundness	Subrounded to subangular irregular elongated and angular types were more predominant in these sandstones than in the Macquarie Park Sandstone	Mainly subangular
Rock fragments	Sedimentary rock fragments were predominant although traces of Saccharoidal lava fragments similar to those found in the lower formations were found in most samples (Table II). Two types existed : 1. Fine red siltstone consisting of fine angular quartz cemented by iron oxide 2. Shale consisting of colloidal size quartz and illitic clay	Sedimentary rock fragments were dominant, but tended to merge with the clay matrix. Saccharoidal lava fragments rare
Matrix	A high matrix content compared with the sandstones of the lower formations	A very high matrix percentage is characteristic (average thirty per cent)

Plant remains resembling the genera *Archaeopteris* or *Rhacopteris* are abundant in the green siltstones and shales.

There is a considerable increase in thickness in the Kurrool Formation from Blathery Creek, westwards to the western limb of the Catombal Syncline (Fig. 2). The Kurrool Formation increases in thickness from 450 feet at Blathery Creek to 1,000 feet three miles further west in the vicinity of the western limb of the Catombal Syncline. This increase in thickness towards the west corresponds with a similar increase in thickness to the west in the underlying Macquarie Park Sandstone.

Bedding in the Kurrool Formation is poorly preserved in the exposed outcrops due to the easy erosion of finely fractured siltstones. Where the bedding is preserved, it has a similar nature to the bedding of the Macquarie Park Sandstone. Coarser members of the Kurrool Formation (medium to fine sandstones) are often quite massive with beds from one to two feet in thickness. However, sandstones are poorly developed and dispersed between greater thicknesses of siltstones which often fail to outcrop. Where the siltstones do outcrop, their bedding thickness is often obscured by the development of a closely spaced fracture cleavage.

Current bedding was only observed in the very coarsest sandstone members and most of these beds were less than two feet in thickness. Ripple marks were the dominant sedimentary structure, being preserved on the faces of many coarse siltstone and fine sandstone beds.

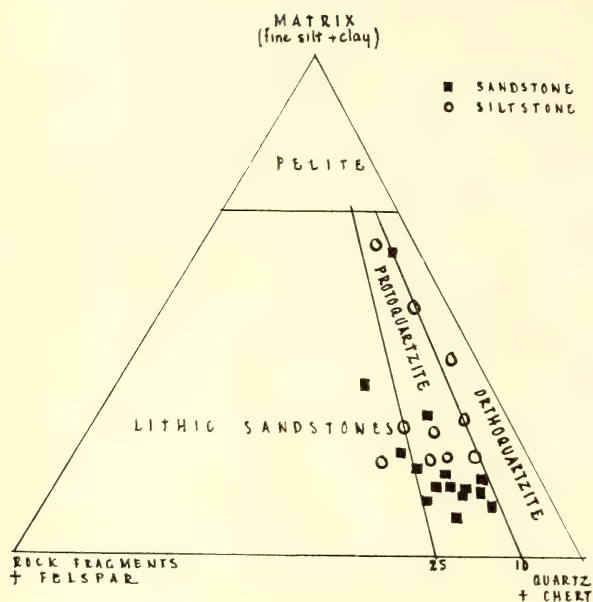
Grain size studies were made from thin sections as the rocks of the Kurrool Formation were too hard for mechanical disintegration. The Kurrool Formation is characterized by sediments with a median grain size between 0.15 and 0.05 mm. and most samples have a sorting coefficient within the range 1.25 to 2.0, indicating that they are reasonably well sorted and have undergone a considerable amount of reworking within the area of deposition.

PETROLOGY

Sandstones and siltstones were examined. The results are shown in the above table.

Point counter analysis (Fig. 5 and Tables II and III) shows that orthoquartzites are rare and that most samples plot in the protoquartzite and lithic sandstone fields on the triangular diagram.

It is interesting to note that although the triangular diagram was only proposed for sandstones, medium to coarse siltstones of the Kurrool Formation have the same type of distribution as the sandstones. The fine sandstones and coarse siltstones of the Kurrool Formation are mainly protoquartzites. They contain slightly less rounded clastic particles than earlier formations in the Black Rock Sub-Group and have a slightly higher sorting coefficient and percentage matrix. They have an abundance of sedimentary but very few volcanic rock fragments and have a red colour due to the dominant iron oxide cement.



COMPOSITION OF 15 SANDSTONES AND 10 SILTSTONES FROM THE KURROOL FORMATION. CALCULATED FROM POINT COUNTER ANALYSIS...

FIG. 5

The Curra Creek Conglomerate

The Curra Creek Conglomerate is the topmost formation of the Catombal Group in the Catombal Range. The formation consists of massive red conglomerates interbedded with red and green siltstones and sandstones.

The Curra Creek Conglomerate is best developed in the northern part of the Catombal

Range along the main eastern belt. As the formation is not overlain by any other formation, erosion must have removed some, or most of its topmost members, and hence measured sections only show a preserved thickness.

The type section for the Curra Creek Conglomerate was measured along the main west road to Yeoval out of Wellington, where Curra Creek cuts through the Catombal Range. The Curra Creek Conglomerate has a total thickness of 3,200 feet and can be subdivided tentatively into three members in the type area. These members are:

1. An upper member with a thickness of 1,050 feet. This member consists of lithic sandstones and siltstones with four distinct thick conglomerate beds.
2. A middle member with a thickness of 450 feet. This member consists of massive conglomerates which are interbedded with several thin sandy and silty layers.
3. A lower member with a thickness of 1,700 feet. This member consists of many thin but massive conglomerate lenses interbedded with red and green siltstones. Coarse sandstones are rare in this lower member.

The writer proposes to call the middle member the Blathery Creek Member, for it is best preserved 12 miles to the south of Curra Creek where Blathery Creek cuts across the eastern part of the Catombal Range, and where it attains a maximum recorded thickness of 500 feet of massive red conglomerate. This member can be traced from Bushranger's Creek in the north southwards for 20 miles to Two Mile Creek, where the Curra Creek fault truncates it.

TABLE II

Composition of Sandstones from the Kurrool Formation Calculated from Point Counter Analysis of Thin Sections

Sample Number and Locality	Quartz	Metamorphic Quartz	Sedimentary Rock Fragments	Volcanic Rock Fragments	Matrix	Secondary Quartz
Bushranger's Creek 028(a)	40	3	25	trace	32	trace
" " 028(b)	57	1	14	trace	28	trace
" " 029	64	3	22	0.5	10	0.5
" " 025(a)	33		7		60	
Catombal Creek 261	66	0.5	19	0.5	14	trace
Blathery Creek 119	70	3	14	trace	13	trace
" " 296	59		33	trace	8	trace
" " 297	65	trace	18	trace	17	trace
" " 298	68	trace	17	trace	15	trace
Dark Corner Creek 142	71	0.5	19	1.0	3	5.5
Catombal Syncline 203	57		23	trace	20	trace
" " 204	62	trace	20	0.5	17	0.5
" " 209	79		11		10	
" " 212	74	trace	13	trace	13	trace
Stables Creek 124	76		12	trace	12	trace

TABLE III

*Composition of Siltstones from the Kurrool Formation
Calculated from Point Counter Analysis of Thin Sections*

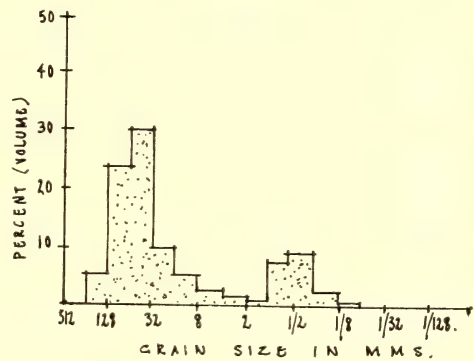
Sample Number and Locality	Quartz	Sedimentary Rock Fragments	Volcanic Rock Fragments	Matrix
Maryvale 272 ..	70	7	trace	23
Bushranger's Creek 030	66	13	trace	21
Dark Corner Creek				
143	66	14	trace	20
141	65	17		18
145	60	15	trace	25
Catombal Syncline 198	55	20		25
" " 200	35	6		59
" " 201	45	7	trace	48
" " 202	64	12	trace	24
" " 208	55	27		18

The Blathery Creek Member thins rapidly to the southern of Blathery Creek and at Two Mile Creek only a few thin conglomerate lenses remain. The lower and upper members of the Curra Creek Conglomerate may come together north of Bushranger's Creek for the middle massive conglomerate similar to the Blathery Creek Member is missing. The Curra Creek Conglomerate thins southward to Two Mile Creek. Massive conglomerate does not occur in the sequence in the Larras Lee-Molong area. To the west in the vicinity of the Catombal Syncline the Curra Creek Conglomerate seems to thin rapidly, and massive red conglomerate lenses are not developed. Two or three buff coloured conglomerates are formed at the very top of the Curra Creek Conglomerate in the centre of the Catombal Syncline, but these conglomerates do not resemble the type of red conglomerate developed in the eastern part of the Catombal Range.

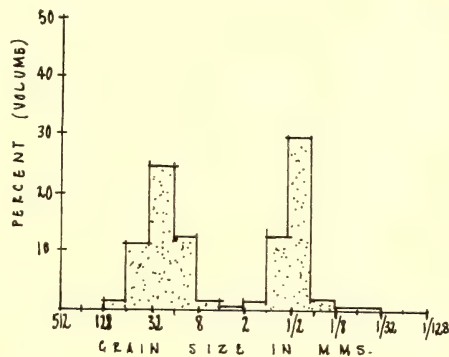
The massive red conglomerates vary considerable in thickness. Individual layers of the Blathery Creek Conglomerate Member are often 40 or 50 feet thick. Normally conglomerate beds tend to be between five and 15 feet in thickness and beds thinner than three feet thick are extremely rare. Massive coarse to fine sandstones are well developed within the Blathery Creek and upper members. Sandstone beds are usually one to three feet in thickness but coarser sandstones may be 10 feet in thickness. The red and green siltstones are finely bedded. Small layers of very fine sandstone are often interbedded with small layers of siltstone. The thickness of these layers varies from three inches to one foot, and the small siltstone-fine sandstone cycle may be

repeated dozens of times within 50 feet of sediment.

Sedimentary structures such as current bedding and ripple marks are rare within the Curra Creek Conglomerate. Occasionally sandstones may show evidence of current bedding in small units, while some wave and current ripple marks have been observed on the bedding planes of siltstone slabs in the lower member of the Curra Creek Conglomerate. Mud cracks have been observed on several occasions in fine siltstones. Scour and fill structures are the characteristic sedimentary structure of the Curra Creek Conglomerate. These structures are often developed at the base of large conglomerate beds and were probably formed when the erosive power of streams had been strong enough to scour out unconsolidated siltstone before depositing the main conglomerate mass. They tend to occur over a large area (hundreds of feet) with gradual angular contacts with the underlying beds.



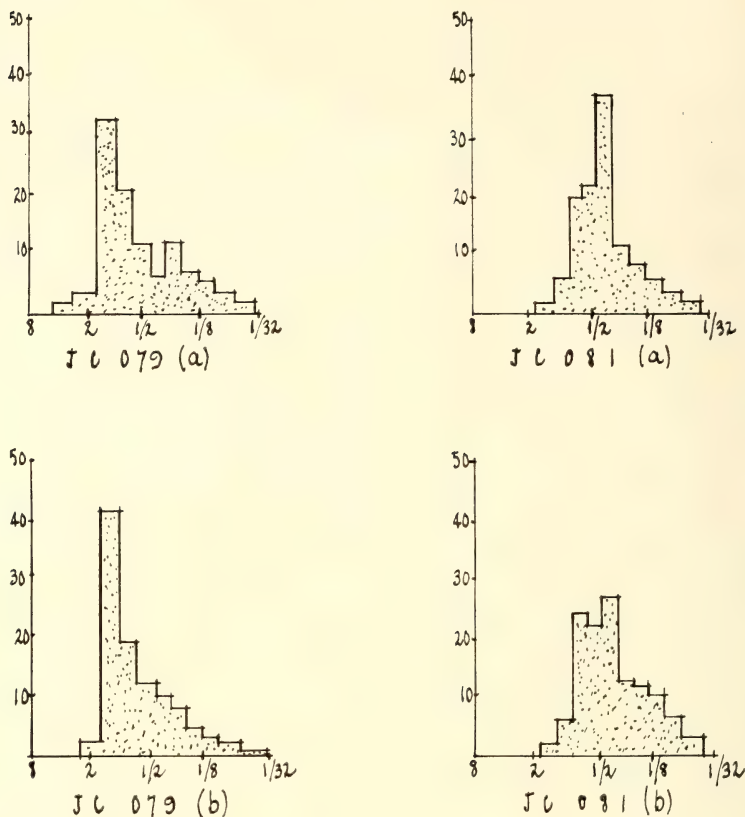
No. 1



No. 2

HISTOGRAMS OF CONGLOMERATE
MEMBERS FROM THE CURRA CREEK
CONGLOMERATE.

FIG. 6



HISTOGRAMS OF FOUR SEIVED SAMPLES OF CURRA CREEK CONGLOMERATE - percentage by weight plotted against grain size in mm.

FIG. 7

GRAIN SIZE DISTRIBUTION

Conglomerates—The conglomerates of the Curra Creek Conglomerate consist of well rounded pebbles which range in size from 16 to 250 millimetres (half an inch to 10 inches). Most pebbles have a diameter from 75 mm. to 25 mm. (four inches to one inch).

The ratio of pebble percentage to matrix percentage also varies considerably. Most conglomerates have a high pebble percentage with little matrix. Histograms of two typical conglomerates are shown in Fig. 6. The first conglomerate (No. 1) is a conglomerate of high pebble content (80%) and a matrix which is fairly well sorted coarse sandstone. The second conglomerate (No. 2) has a higher matrix content than the first and tends to be finer grained in

both the primary and secondary modes. Most authors explain the coarse primary mode as the traction load rolled along by currents carrying the finer sandy material of the secondary mode in suspension. Bimodal histograms such as these are reported by Pettijohn (1949, p. 40) to be of a fluvial origin, while most marine conglomerates are unimodal. General conclusions can be made about the grain size distribution in Curra Creek Conglomerates:

Most thickly bedded conglomerates contain large pebbles (about four to 10 inches in diameter) and have a high pebble content (80% or more). They normally have coarse sandstone as a matrix.

With decrease in bedding thickness the size and number of the pebbles decrease until

thinly bedded conglomerates (three to four feet) may have only 30% pebble content and the rest would be interstitial medium sand.

All conglomerates have a bimodal distribution with a coarse pebble primary mode and a medium to coarse sand secondary mode. For this reason the writer considers they are of fluvial origin, the pebbles representing a traction load with the sandstone matrix representing detritus that later settled between pebbles.

Sandstones—Sandstones of two main types occur: (a) Associated or interbedded with conglomerate beds; (b) dispersed throughout the formation at sporadic intervals. Figure 7 shows histograms of four typical sandstones from the Curra Creek Conglomerate.

The median grain size ranges from 1.02 to 0.47 mms., so these samples are coarse grained sandstones. Sorting coefficients range from 1.73 to 1.58 mms. These values are higher than any values recorded from samples from previous formations of similar grain size. They are not well enough sorted to be marine sandstones, but are more probably river or flood plain sands closely associated with conglomerates.

Sandstones belonging to the second group have not been studied in detail by sieving, but some general results have been obtained from thin sections.

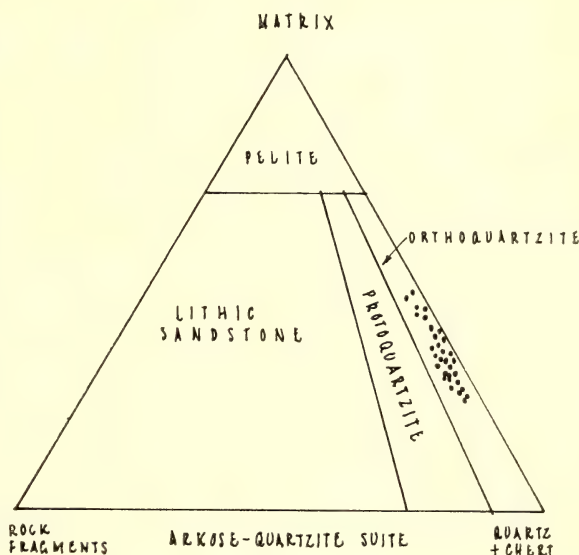
They are normally fine to medium grained sandstones with a tendency for most to be fine grained. They have a similar grain size to the sandstones from the Kurrool Formation.

It is possible that the Kurrool Formation lithology will continue on into the Curra Creek Conglomerate, particularly in the lower member and that with intercalation of coarser detritus (such as beds of conglomerates) there will be a tendency for an increase in grain size amongst associated sandstones.

Siltstones—Siltstones make up a great proportion of the bulk of the Curra Creek Conglomerate. From comparison with thin sections of siltstones from the Kurrool Formation, the following conclusions could be made:

The siltstones of the Curra Creek Conglomerate have a similar grain size distribution as the siltstones of the Kurrool Formation, being coarse grained siltstones with median diameters that range from 0.06 to 0.03 mm.

The siltstones in the middle and upper members of the Curra Creek Conglomerate are not as well sorted as the siltstones of the lower members.



TRIANGULAR DIAGRAM SHOWING THE COMPOSITION OF 26 COARSE SILTSTONES AND FINE SANDSTONE PEBBLES FROM THE CURRA CREEK CONGLOMERATE.

FIG. 8

PETROLOGY

The petrology of the conglomerates was studied by collecting samples of various matrix and pebble types from many different localities. Two types of conglomerate were found. The first and main type was the massive oligomictic red conglomerate that is characteristic of the whole formation. The second type was found in small lenses interbedded with the rest of the formation and contained many reworked limestone fragments.

Oligomictic Red Conglomerates—Pebbles of these conglomerates consist almost completely of one rock type only, a very fine quartz sandstone to coarse quartz siltstone. The only other pebble types recorded are fine cherts and large quartz pebbles. The pebbles are mainly ellipsoidal or pear-shaped and well-rounded, indicating lengthy transport and consolidation in the source area before transportation.

Twenty-six petrographic analyses were made from characteristic pebble types over the total outcrop area (Fig. 8).

These analyses show:

1. A variation in grain size from 0.02 to 0.13 mm. with a definite mode for most samples at about 0.07 mm.

2. All samples are orthoquartzites consisting of subangular quartz grains in a clay matrix and often cemented by hematite.

It is probable that most of the clay matrix is a disintegration product of sedimentary rock fragments, although not many actual fragments could be found. The pebbles have a different composition to any other rock type found in the Catombal Group (Fig. 8).

In the Catombal Syncline area the conglomerates are only sparsely developed. They contain a fairly high percentage of siliceous or chert pebbles. This suggests that there is a change in facies in an east-west direction across the Catombal Range, but since there is a possibility that most of the Curra Creek Conglomerate which was originally in the centre of the Catombal Syncline, has been eroded away, no definite conclusions can be reached. The matrix of the conglomerates consists of coarse to medium lithic sandstones. These are discussed in detail with the other sandstones of the Curra Creek Conglomerate.

Calcareous rudites—These rocks occur in the lenses one to two feet in thickness. These lenses are not very persistent, some persist for only about 25 yards along the strike. They are composed of irregular calcareous and siltstone fragments and their median grain size varies from eight to one millimetre, but is normally between two to four millimetres. The rocks are cemented by hematite, giving them a rich red colour (Plate III, 4).

Six thin sections of samples from different localities within the Two Mile Creek-Molong area have the following range in composition :

Calcareous rock fragments	55–85%
Siltstone rock fragments ..	10–30%
Shale rock fragments ..	0–10%
Detrital quartz	4–15%
Iron oxide cement	1– 8%
Calcite cement	0–15%

The calcareous rock fragments are quite often recrystallized and in some cases it was hard to tell whether they were rock fragments or just accumulations of calcareous material. Recent publications by various authors on the composition of limestones enabled Folk (1959) to propose a most useful and practical classification of limestones. The use of this classification has enabled the writer to recognize definite relic structures in the calcareous fragments, hence showing that the calcareous detritus was derived mainly from previous limestone (Plate III, 4). The main type of relic structure was one where pellets or algal fragments of finely

crystalline calcareous material were cemented by a more largely crystalline calcite cement called "sparry calcite" by Folk. Other relic limestone fragments were hard to identify. Another fairly common type of limestone fragment consists of very fine calcite and clay material, with a massive texture. Folk calls this type of limestone a "micrite" or a "micritic limestone"—resembling an accumulation of lime-mud. Detrital quartz is always present and is normally of coarse silt to fine sand size. The grains are subangular to angular. Siltstone and shaly rock fragments are also common components. Hematite coloured the matrix, siltstone and shaly fragments, and often the limestone fragments. Calcite cement was sometimes present, replacing the hematite cement. The detrital fragments of this rock are always extremely angular and often showed crumpling and bending that must have occurred during, or just after deposition. Quite often siltstone rock fragments are completely bent around calcareous detritus. There is no obvious alignment of particles along bedding planes.

The overall texture of the rock suggests that it is a local "dump" deposit where partly consolidated limestone and siltstone fragments were buried under other detritus before they could be dissolved away. The beds above and beneath these calcrudite lenses were usually coarse siltstone or fine sandstone similar in grain size to that of the small amount of detrital quartz which is present in the calcrudite. No calcareous material was found in the rocks above or beneath the calcrudite lens, hence it must be assumed that the advent of limestone detritus was caused by floods carrying limestone derived from a nearby partly consolidated source rock.

The limestones of the Garra Beds are extremely abundant in the Larras Lee-Molong area. The writer has observed pelletal limestones amongst the Garra Beds, while Brachiopod and Gastropod bearing limestones are also abundant. The Garra Beds may have formed local highs close to the area of deposition that were eroded to form the limestone detritus for the calcrudite lenses.

Sandstones—

1. *Quartz*: Once again, non-stressed quartz with numerous gaseous and liquid inclusions is more abundant than the polycrystalline variety which was never greater than 3% and normally less than 1% of the total volume of the rock. Most grains were subrounded to subangular, only the larger grains ever showing extensive rounding (Plate I, 4).

2. *Rock fragments*: Two prominent types of rock fragments occurred:

(a) *Siltstone rock fragments*: These fragments consisted of fine angular quartz in a clay or iron-stained clay matrix and are probably smaller "relatives" of the orthoquartzite pebbles that dominate the lithology of the oligomictic conglomerates (Plates II, 3 and 4).

(b) *Shale rock fragments*: These fragments consisted of fine colloidal quartz and illitic clay. They were very fine grained (one to 10 microns), brown or buff coloured, or, occasionally, had a red colour caused by iron oxide staining. They must have been partly consolidated or very soft, for they were normally flattened along the bedding plane (Plate I, 4).

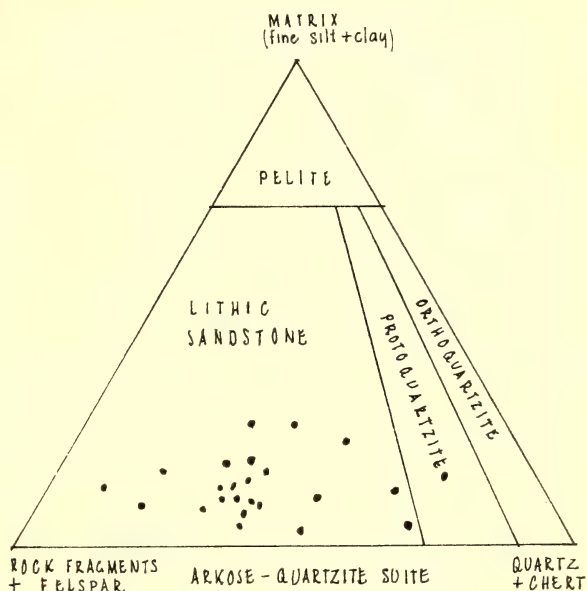
3. *Matrix*: The matrix of these sandstones consisted of broken pieces of shale and siltstone rock fragments and patches of authigenic kaolinite. The matrix percentage was never very high for shale fragments were able to accommodate open spaces by bonding or breaking into them (Plate I, 4).

4. *Textures*: Two predominant textures were observed in thin section:

(a) The coarse sandstones that occurred associated with conglomerates had a high siltstone rock fragment percentage and less shale fragments. Tangential contacts between grains or "floating" grains in a clay matrix is a common texture (Plate II, 4).

(b) The medium to fine sandstones that were associated with the lowest and uppermost of the Curra Creek Conglomerate had a high shale fragment percentage. The shale fragments were not very competent and during consolidation they were crushed between more competent quartz and siltstone fragments producing a "welded" texture. The shale fragments eventually became lineated with their long axes orientated parallel to the bedding plane (Plate I, 4).

Petrographic analyses of 24 sandstones show that no definite changes in mineral composition could be found along the strike (Fig. 9). The sandstones that plot closest to the rock fragment end member are normally fine to medium grained sandstones with a "welded" texture and an abundance of shale fragments. The coarse sandstones that are associated with conglomerates plot closer to the protoquartzite field. The sandstones of the Curra Creek Conglomerate are "dirty", lithic sandstones with a high unstable rock fragment percentage. They are not as well sorted as the marine sandstones of the Black Rock Sub-Group and



TRIANGULAR DIAGRAM SHOWING THE COMPOSITION OF 24 SANDSTONES FROM THE CURRA CREEK CONGLOMERATE

FIG. 9

contain angular to subangular quartz, suggesting that they are terrestrial sandstones with a high proportion of unstable detritus.

GENERAL Heavy Minerals

Heavy mineral separations from 40 samples of outcropping sandstone within the Catombal Group were prepared on slides and analyses made by counting of grains.

The following heavy minerals were recognized: leucoxene, rutile, limonite, ilmenite, hematite, garnet, zircon, hornblende, tourmaline, apatite, biotite and pyroxene. Of these, leucoxene, leucoxene-limonite and leucoxene-ilmenite complexes are by far the most dominant, totalling in most separations far greater than 50% of the heavy minerals. In some samples, particularly the red sandstones, hematite and hematite-limonite occur as a cement coating the grains.

Only random grains of magnetite occur in a few samples and are completely missing in others.

Ilmenite is a very persistent mineral tending to be well rounded and smaller than associated tourmaline, hornblende or garnet.

In most samples ilmenite represented from 5% to 10% of the heavy mineral concentrate and was frequently associated with leucoxene and leucoxene pellets.

Golding (1955) recognized four basic types of leucoxene in recent dunes at Stradbroke Island, Queensland:

1. Ilmenite-leucoxene complexes;
2. "White opaques";
3. Amber-like grains;
4. Rutile-leucoxene complexes.

The first three groups are present in the Macquarie Park Sandstone, groups 1 and 2 being the most abundant. Rutile-leucoxene complexes are not present and amber-like grains are very rare, while amongst the second group of "white opaques", pitted leucoxene-quartz aggregates are by far the dominant type.

As Golding referred to this last group as one that represented ultimate formation in situ from ilmenite, it would seem that the bulk of the leucoxene types represented have reached a stage of maturity and may well be derived from pre-existing sediments. However, it is noted that in a few samples the ilmenite-leucoxene group is larger than the pitted leucoxene-quartz pellets, and this could then be regarded as almost primary material that has only just started its diagenetic and depositional cycle.

Zircon is a very abundant species tending to concentrate in only the finer fractions. Most of the grains are colourless and euhedral showing slight rounding. Crystals with first and second order prisms and bipyramids are common. Inclusions of ilmenite, rutile, zircon, gaseous and liquid cavities frequently orientated parallel to the crystallographic axes occur in many crystals (Fig. 10).

In some samples, two distinct types of zircon occur: (1) Euhedra with little rounding; (2) oval and elongated grains with extreme rounding.

This immediately suggests that the zircon was derived from at least two distinct rock types, one of which is sedimentary.

Tourmaline is the most abundant species next to zircon. Brown to brown-green grains predominate with rarer blue grains. Pleochroism is most intense in the common brown variety. Most grains are extremely well rounded oval shapes, but some rounded striated, prismatic and irregular subangular grains also occur. The tourmaline in this suite is typically without many inclusions but with characteristic vacuoles

or cavities. Krynine (1946) considers that this type of tourmaline is of ultimate igneous origin.

Rutile is a very persistent, although a not so abundant mineral. Grains are well rounded to subrounded with elongate, oval and irregular outlines. Colour tends to be a soft brown-red to red. No extremely dark or black varieties occur. Most rutile grains are dichroic with intense absorption parallel to the C axis.

Hornblende grains occurring as elongated and irregular platy cleavage flakes are common in the larger fraction of almost every sample and also occur in the fine fractions. The mineral has strong pleochroism from green and olive-green shades to a very strong brown colour. In this case it was hard to distinguish brown pleochroic tourmaline from hornblende; however, grains with biaxial negative figures and extinction angles of two to three degrees were identified as the basaltic hornblende, basaltine. The grains are fresh, sometimes with inclusions of iron ores, and prismatic needles of zircon. Several platy grains have frayed ends determined by the (110) cleavage, but mainly the grains showed evidence of some transport, having an irregular shape with some portions slightly rounded (Fig. 10).

Garnet. This mineral occurs in several samples and in each case it is one of the abundant heavy minerals. In one sample 55% of the heavy mineral fraction (after extraction of iron oxides) was garnet. The garnet has a large variety of external form and shape, with grains mainly of an irregular shape, bounded by conchoidal fracture surfaces. These surfaces are pitted, grooved, spotted, or had patterns of pits of different sizes, and on many occasions are shaped by a pseudo-cleavage of a rectangular nature (Fig. 10). The colour ranges from almost colourless to pale pink, so the mineral probably belongs to the spessartite-almandine series. Inclusions occur in most grains, iron ores, zircon, rutile, quartz and feldspar being noted. Almost all grains are confined to a size between 0.3 mm. to 0.1 mm.

Apatite. Most apatites were pea-shaped grains with well rounded pitted surfaces. Elliptical to sub-spherical forms are dominant, although the hexagonal prismatic habit is sometimes seen in some grains that have equant or hexagonal outlines (Fig. 10). Their refractive index is high but birefringence low, only whites and occasionally browns of the first order being developed. They are uniaxial negative and they have a dull white appearance due to many liquid or gaseous inclusions.

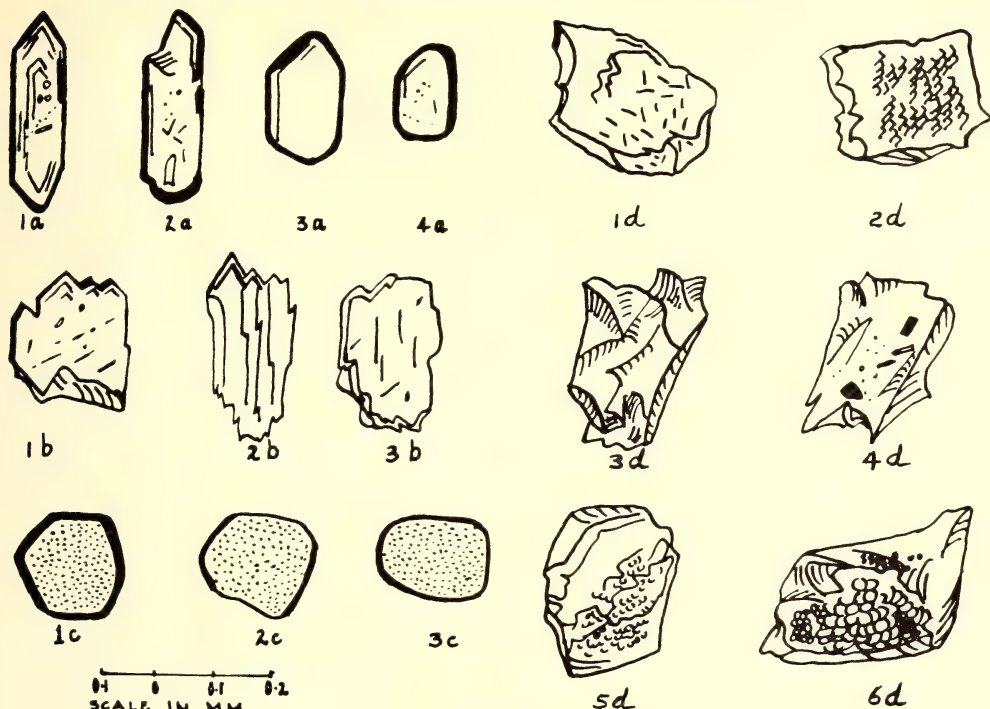


FIG. 10

Typical heavy mineral grains from the Catombal Group. (a) Zircon; (b) Hornblende; (c) Apatite; (d) Garnet

Biotite. This is not a very common heavy mineral in this suite, but occurs in characteristic irregular cleavage flakes which tend to lie with the (001) cleavage on the plane of the slide. Pleochroic haloes can be recognized and the dominant colour is a deep brown. The grains tend to be quite small but not a sufficient number of grains was seen to be sure that this small size is an important feature.

Heavy Mineral Accessories. Other heavy minerals that were identified included: pyroxene, sapphire, monazite, chalcedony, white mud and frequent rock fragments and composite grains of heavy minerals with quartz.

Van Andel (1959) discussed the use of heavy minerals as an aid to studies in sedimentary correlation and provenance. He listed four factors that could modify the composition of the heavy mineral assemblage and hence give poor results:

1. Weathering, either in the source area, or after deposition above the watertable in permeable sands or gravels.
2. Selective mechanical destruction during transportation.
3. Selective sorting during transportation, many species showing a preference for certain size ranges.

4. Post-depositional solution. Pettijohn (1957) considered this to be one of the greatest factors against the use of heavy minerals for correlation but other authors regard this phenomenon to be of only very local importance.

Van Andel concludes that in any comprehensive study with many samples the four factors mentioned will not impair the quality of the results obtained.

The only extraneous heavy minerals found in the studies in the Catombal Group were limonites, most of which were probably formed due to weathering above the watertable in permeable sandstones, although some may be authigenic formed in an earlier stage of sedimentation. It is also possible that many limonites are actually goethites, for in some badly weathered samples goethite was found in the matrix fraction and gave characteristic peaks on differential thermal analysis. Leucoxene and leucoxene-ilmenite composites seem to be partly detrital and partly authigenic originating from detrital ilmenite. Hematite occurs as a coating or detrital grains and as such forms a cement in many sandstones and siltstones. The remaining heavy minerals are the more important for correlation and pro-

TABLE IV

Approximate Percentages of Common Heavy Minerals in the Catombal Group, Wellington
(Leucoxene, Limonite, Hematite and Ilmenite are excluded)

Formation	Zircon	Garnet	Rutile	Tourmaline	Hornblende	Apatite
Brymedura Sandstone	40	30	20	5	5	
Macquarie Park Sandstone	35	25	15	15	5	5
Kurrool Formation	75	5	trace	5	5	10
Curra Creek Conglomerate	30	45	15	10	trace	trace

venance studies, the most common minerals among this category being: zircon, garnet, rutile, tourmaline, hornblende and apatite. It is noteworthy that all these minerals (except apatite) are persistent throughout all formations in the Catombal Group (Table 4).

Pettijohn (1947, p. 98) lists typical heavy mineral suites. Among those heavy minerals found in reworked sediments, leucoxene, tourmaline, zircon and rutile are prominent. These minerals are well represented in the Catombal Group, and can be correlated with the abundance of sedimentary rock fragments.

Provenance

The occurrence of garnet was interesting. Although the source rocks for this mineral usually are high rank metamorphic or pegmatitic, the author considers that the garnet is derived from the abundant garnetiferous tuffs and lavas that occur in a north-south trending belt about five to 10 miles west of the Catombal Range. The reasons for this are:

1. The garnet in these "tuffs" is an almandine variety, the same as that found in the heavy mineral suites.
2. The high proportion of garnet in the heavy mineral suite suggests that it has not travelled very far. If it was derived from reworked sediments, a much lower percentage of garnet would be expected.
3. The garnet is not rounded, also suggesting that it has undergone little transportation.

The basaltic hornblende which presumably was derived from basic lavas or intrusives is common throughout the succession. Thin sections show that tuffaceous and basic igneous rock fragments are fairly common throughout the Catombal Group. The occurrence of pyroxene and biotite also suggests that rocks of a basic or intermediate igneous origin were present in the source area. The hornblende is not very rounded, suggesting a close source area. Such a source area is not hard to find, for belts of andesite and associated lavas are common

both to the immediate east and west of the Catombal Range. Well rounded apatite grains are most probably reworked from sedimentary rocks or they may well have suffered extensive transportation from a primary granite. Hence, the heavy minerals of the Catombal Group are of not much use for correlation between one formation and another but they represent a suite of their own (Table IV). They do suggest an area of provenance containing the following source rocks:

1. Sedimentary rocks, with zircon, rutile, tourmaline, apatite, leucoxene and ilmenite.
2. Basic to intermediate lavas, yielding basaltic hornblende, with scattered grains of biotite and pyroxene.
3. Garnetiferous tuff horizons, yielding fresh faintly pink almandine garnet.

Diagenesis

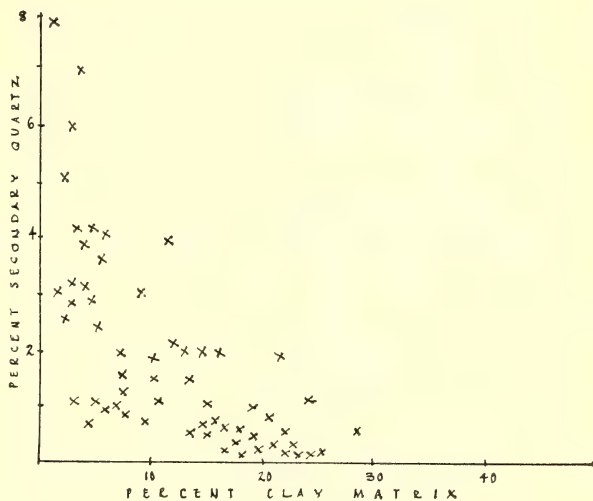
Dapples (1959) considers that quartzose sandstones tend toward equilibria under three different stages of diagenesis.

- (a) During deposition, there is a distinct pitting and rounding of quartz grains by solution.
- (b) Early burial is characterized by precipitation of quartz as overgrowths.
- (c) Late burial is characterized by addition of carbonate cement, sometimes as a replacement of quartz grains. When carbonate is absent interpenetration of quartz grains increases with depth of burial or application of pressure due to tectonic forces.

Examples of sandstones representing all three stages are found in the sandstones of the Catombal Group. In general the rocks of the Black Rock Sub-Group are more quartz-rich and have larger amounts of authigenic silica than the quartz-poor rocks of the Canangle Sub-Group which have considerably high percentages of authigenic iron oxide. Within the Black Rock Sub-Group the problem of diagenesis involves cementation by silica and the deposition and subsequent alteration of clay minerals. Carbonate is absent except in the calc-silicate

rocks at the base of the Macquarie Sandstone at the northern end of the Catombal Range, where it replaces earlier quartz overgrowths in a similar fashion to stage three (mentioned above). The Brymedura Sandstone is a loosely packed well sorted sandstone with tangential or straight grain contacts or "floating" grains. Pore space between the detrital grains is mostly filled by secondary silica (Plate I, 1, III, 3). An average of 5% by volume of secondary silica is estimated to be present in most Brymedura Sandstones. Although interpenetration of grains is not common, it occurs in the vicinity of strike faults. Kaolinite and illite are present as authigenic clay minerals. In some sandstones illite occurs between original detrital grain outlines and secondary quartz outgrowths, but mostly kaolinite and illite are present in patches between secondary quartz. Iron oxide is rarely present except as a thin coating on detrital grains.

The Macquarie Park Sandstone also has large amounts of authigenic silica and clay matrix and little iron oxide cement. However, the finer grain sized Macquarie Park Sandstone characteristically has a sutured or interlocking texture caused by interpenetration of quartz grains (Plate I, 2). Petrographic analyses of many thin sections show that with a decrease in grain size there is an increase in the percentage clay matrix and a corresponding decrease in the percentage of authigenic silica (Fig. 11). The volume of silica lost due to pressure solution processes is probably deposited in the more porous sandstones within the sequence. Preliminary clay mineral investigations show that the finer sandstones and also the shales of the Macquarie Park Sandstone contain mostly illite, some kaolinite and a fair amount of chlorite or mixed layered material, whereas the more porous coarser grained sandstones have a higher proportion of kaolinite, most probably due to surface leaching processes. In the sediments of the Canangle Sub-Group, authigenic silica is only a minor constituent, whereas iron oxides are the important authigenic minerals. The abundance of clay matrix and sedimentary rock fragments enabled most detrital quartz grains to be kept apart (Plate I, 3 and 4), hence the amount of pressure solution between adjacent quartz grains was low in comparison to the rocks of the Black Rock Sub-Group. Iron oxide is the dominant authigenic mineral apart from clay and is characteristically developed in patches. Most of the iron oxide is hematite, which alters to limonite and sometimes goethite when the rock has been subjected to surface



SECONDARY QUARTZ - CLAY MATRIX
RELATIONSHIP FROM POINT COUNTER
ANALYSIS OF 60 THIN SECTIONS OF
MACQUARIE PARK SANDSTONES . . .

FIG. 11

weathering. It seems to originate from iron-rich detrital sedimentary particles with which the iron oxide cement is closely associated in the present rock. The finer sediments (siltstones) have a higher iron oxide content than the coarser sediments (sandstones). Most of the clay matrix of the sediments of the Canangle Sub-Group is primary detrital material that has been subjected to strong leaching processes with the necessary formation of kaolinite and hematite.

CORRELATION WITHIN THE CATOMBAL GROUP

The detailed correlation of rock units established in the field was made from both palaeontological and petrological correlations.

PALAEONTOLOGICAL APPROACH

The Black Rock Sub-Group could be correlated from Molong to Wellington on the presence of a brachiopod fauna with the common genera, *Cyrtospirifer* and *Camarotoechia*. In certain localities plant remains belonging to the genus *Lepidodendron* and fishplates referable to the genus *Bothriolepis* occur within the same sequence. The age of this fauna is Upper Devonian.

The Canangle Sub-Group sediments can be correlated from Molong to Wellington because

plant fragments referable to the genera *Archaeopteris* or *Rhacopteris* are restricted to these rocks. The age of this flora is considered to be the top of the Upper Devonian, but the author considers that this may be extended into the Lower Carboniferous.

PETROLOGICAL APPROACH

Two petrological parameters have been described in detail and can be used for correlation. They are:

1. The mineralogical composition plotted on triangular diagrams.
2. Amount and type of cementing agent.

Mineralogical Composition—Detailed descriptions of the variety and characteristics of these parameters have already been discussed for each rock unit or formation. Petrological correlation has been mainly based on mineralogical composition in terms of three end members (quartz and chert, rock fragments and feldspar, and clay matrix). Point counter analysis of these components from many thin sections sampled over the outcrop area for each formation have been plotted on the triangular diagram proposed for the arkose-quartzite suite. The usefulness of this technique is well illustrated for the Brymedura Sandstone (Fig. 3). The homogeneity of this formation found from study of field outcrop material such as grain size, bedding, cross bedding and thickness is found to be exemplified by thin section study. All samples from over 50 miles of strike length lie within a small area on the triangular diagram. This shows that for this formation thin section study is just as useful in correlation as field lithology comparisons. The writer considers that the identification of the Brymedura Sandstone could be made from any other formation in the Catombal Group by examination of thin sections.

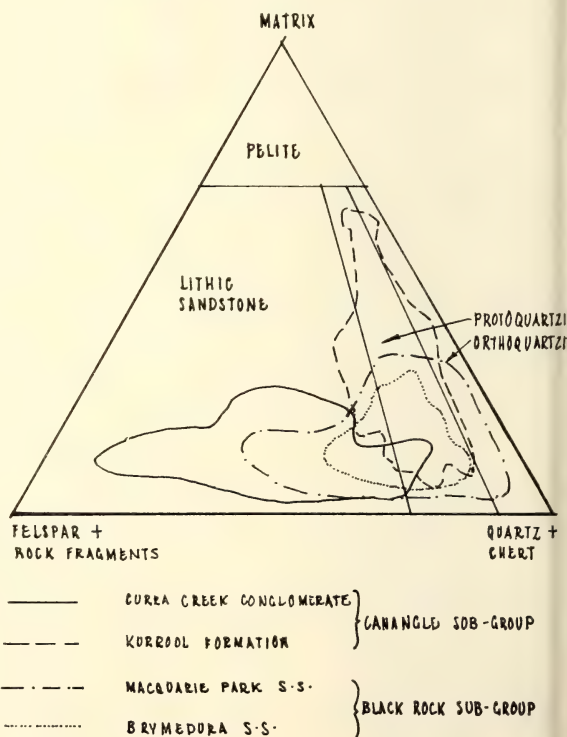
The range of mineralogical variation found within four formations of the Catombal Group is shown in Fig. 12. The following results are apparent:

- (a) The Brymedura Sandstone and Macquarie Park Sandstones have a similar modal mineralogical composition, but the Kurrool Formation and Curra Creek Conglomerate have different modal compositions.
- (b) The Brymedura Sandstone and the Macquarie Park Sandstone form a distinctive mineralogical suite. They have a similar modal composition with a high percentage of quartz (average 70%), relatively low

matrix (15%) and relatively high rock fragments (15%). There is more variation within the Macquarie Park Sandstone, mainly caused by the wider range in variation in grain size within this formation.

The Kurrool Formation is mainly fine grained and mineralogical compositions plot in the proto-quartzite and orthoquartzite field with a high percentage of matrix (Fig. 12). They have a fairly wide range of rock fragment composition. This is a reflection on the nature of the sediments within the formation for sandstones at the base of the formation are similar to Macquarie Park Sandstones, which average 15% rock fragments but, towards the top of the formation, lithic sandstones with a high percentage of rock fragments become more frequent.

The Curra Creek Conglomerate sandstones are completely different to sandstones from earlier formations. They are lithic sandstones with a high rock fragment content (20% to 50%), a low quartz content (40% to 60%), and a relatively low matrix content (5% to



COMPOSITION OF SANDSTONES FROM THE CATOMBAL GROUP, WOLONG - WELLINGTON, CALCULATED FROM POINT COUNTER ANALYSIS OF THIN SECTIONS

FIG. 12

15%). Hence it is possible to distinguish the above formations on the basis of the typical mineralogy and texture displayed by sandstones (Fig. 12).

Cement—Two cementing agents are common throughout the Catombal Group: (a) authigenic silica, (b) iron oxide.

The amount of iron oxide cement has been used in an indirect fashion, to subdivide the Canangle Sub-Group from the Black Rock Sub-Group. The "red measures" of the Canangle Sub-Group have an abundance of hematite cement giving the rocks a pronounced red colour, whereas any red colour produced in the Black Rock Sub-Group is caused by a relatively high percentage of coloured rock fragments.

Sedimentation

BRYMEDURA SANDSTONE

The homogeneous nature of the Brymedura Sandstone immediately suggests that it has been aformed under conditions of source rock and transportation stability. It is coarse grained, containing extremely well rounded particles and characterized by coarse current bedding. It was probably formed in a high-energy environment perhaps in the form of a low offshore sand bar where strong longshore currents swept away all but the coarse sand of a grain size of 0.5 mm. or greater. Small but regular variations in stratigraphic thickness, the percentage drop in volcanic rock fragments and matrix, and palaeocurrent directions suggest that the sand bar was derived from the south.

Not only did these variations suggest that the main "bar" was developed in the south but that with increased transport (i.e. with the currents) the percentage of volcanic rock fragments decreased and the sandstones belonged to a more mature type, although still not of orthoquartzite composition. In several localities to the north of Larras Lee where the "bar" thins, banks of broken shells of *Cyrtospirifer* and *Camarotoechia* are preserved.

MACQUARIE PARK SANDSTONE

Although this formation is characterized by fine to medium grained protoquartzites and orthoquartzites which are well sorted sandstones, it is transitional into the red siltstone lithology of the Kurrool Formation. The basal two or three hundred feet of the Macquarie Park Sandstone is interpreted as being mainly sandstones deposited in an offshore marine environment with preservation of shoal banks of species

of *Cyrtospirifer* and *Camarotoechia*. These sandstones are well sorted, and show a high degree of particle rounding in contrast to the red sandstones and coarse siltstones that are intercalated with the upper part of the Macquarie Park Sandstone.

During deposition of this formation the environment fluctuated between "high energy" (offshore or beach) to "lower energy" (lagoonal or lacustrine). The degree of sorting, the amount of rounding and the increase in less resistant sedimentary rock fragments and clay pellets is associated with low amplitude wave ripple marks and small current bedded units. In several localities lenses of green or red shale are intercalated in the sandstones. These bands represent areas within the basin in which only detritus of fine silt or clay size was deposited. Similar areas are commonly found in present offshore and estuarine environments and are dependent on the topography of the basin floor and the direction of the prominent currents. Variation in stratigraphic thickness and petrology show that the lower Macquarie Park Sandstone is a long narrow strip of sediments thickening considerably to the west in the Wellington region but to the east in the Molong region. There was probably an area of relatively higher elevation of the floor of the basin at Larras Lee, separating two main areas of deposition to the north and south. With increase in time there was a gradual regression of the sea to the east and estuarine and lagoonal conditions prevailed, the greatest thickness of sediments being developed in a faster subsiding area, now preserved in the western region of the Catombal Syncline.

KURROOL FORMATION AND CURRA CREEK CONGLOMERATE

The most remarkable feature of the Kurrool Formation is that almost all sediments are coarse siltstones or fine sandstones cemented with iron oxide. Basal Kurrool sediments are characteristically less angular, contain less shale or siltstone fragments, and have a lower clay matrix percentage than the topmost sediments. The environment was probably transitional between "low energy" lacustrine to wholly terrestrial alluvial or fluvial deposits. The presence of hematite cement in almost all sediments indicates an oxidizing environment. Towards the north near Wellington large thicknesses of typical river gravel beds accumulated to form the Curra Creek Conglomerate. Because of erosion in most parts of the succession, no definite facies changes could be traced.

GEOLOGICAL MAP SHOWING THE CATOMBAL GROUP IN THE WELLINGTON REGION.

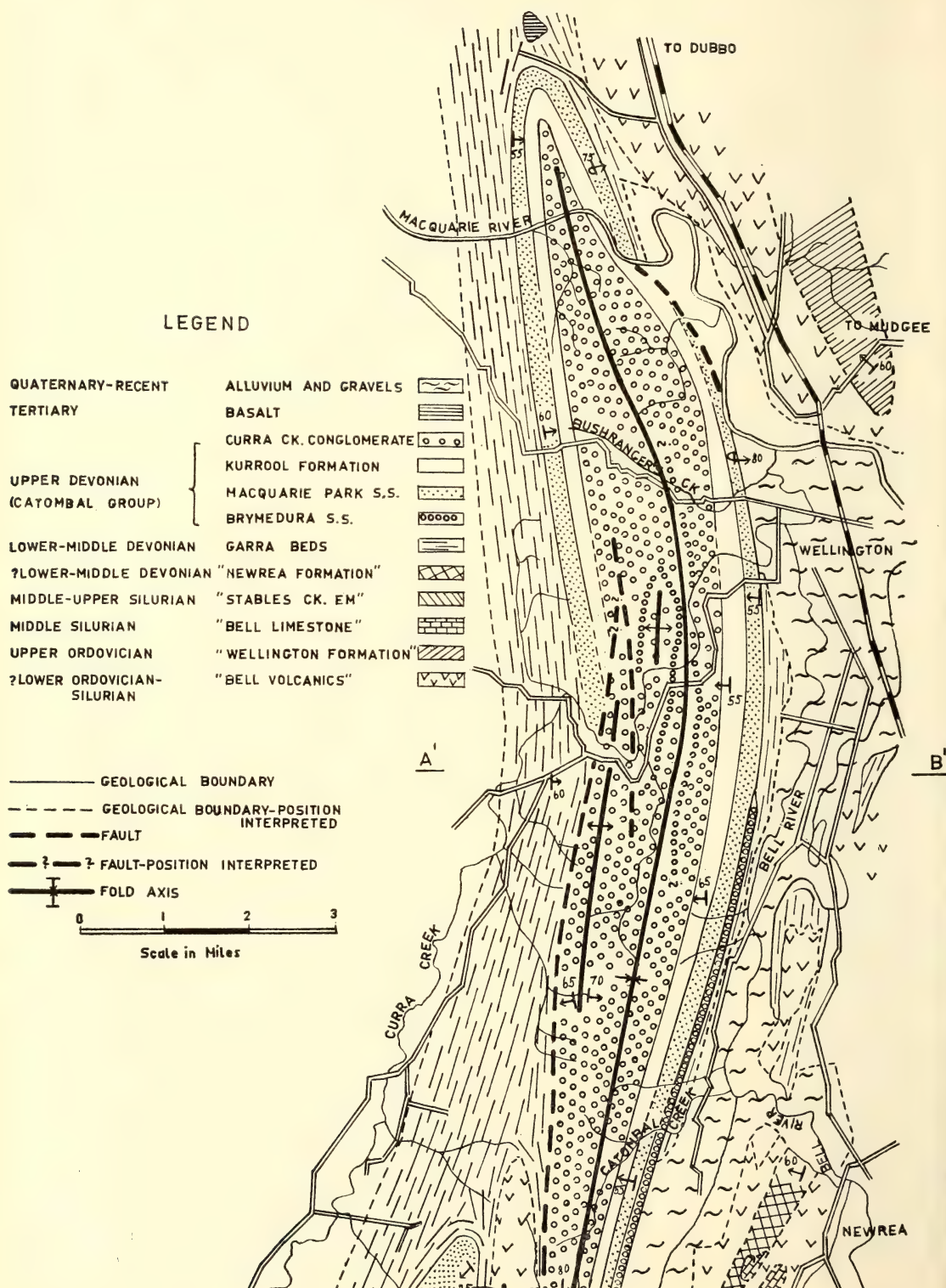


FIG. 13 (continued opposite)

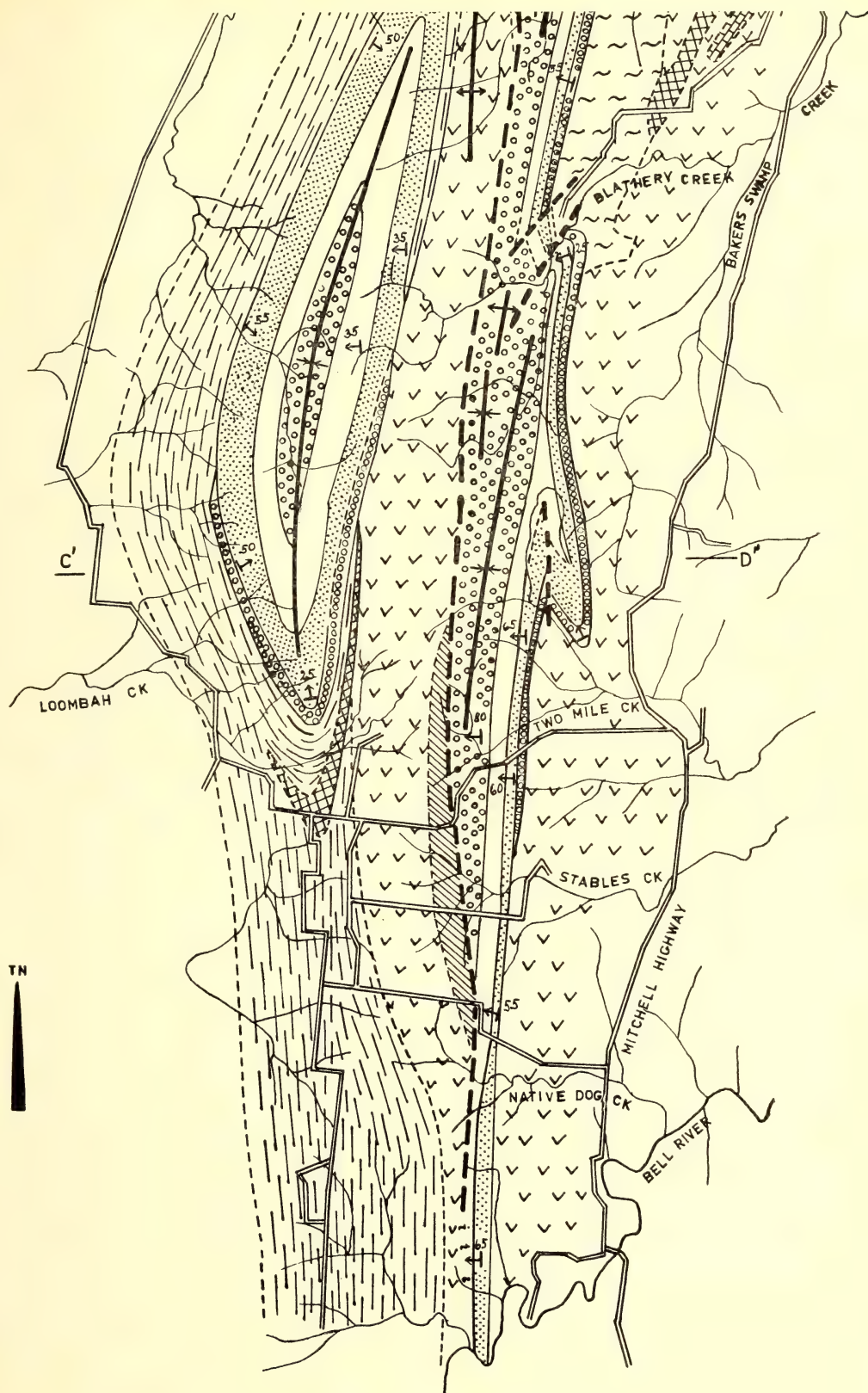


FIG. 13 (continued)

GEOLOGICAL MAP SHOWING THE CATOMBAL GROUP IN THE
LARRAS LEE-MOLONG REGION

LEGEND

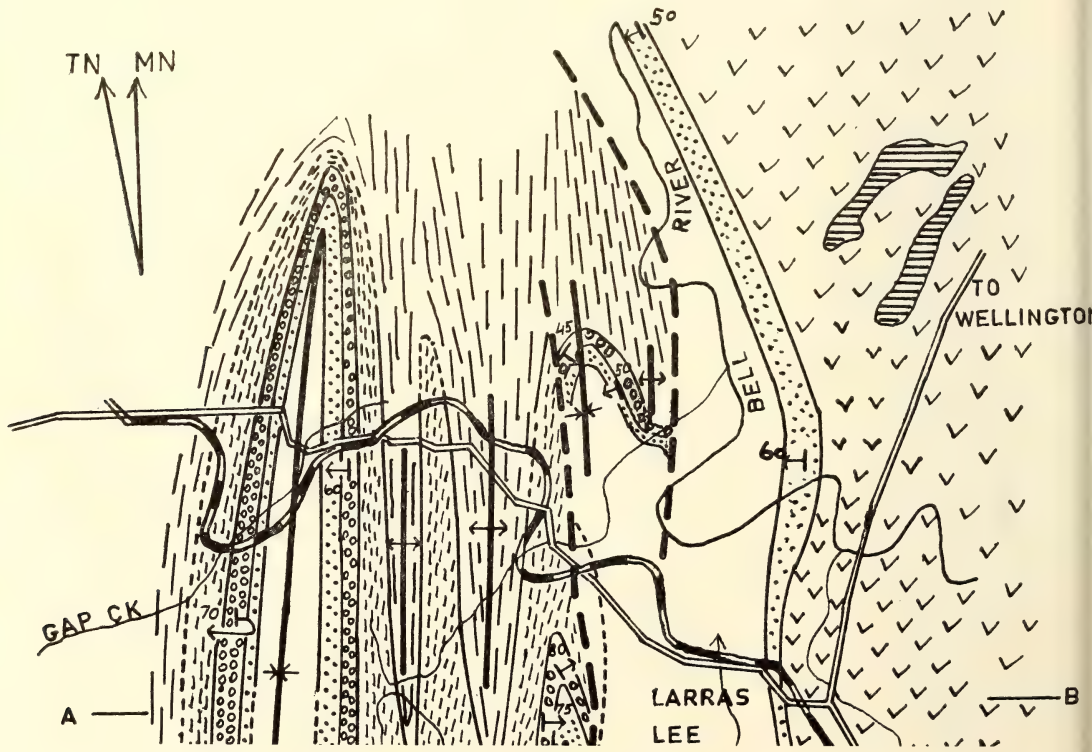
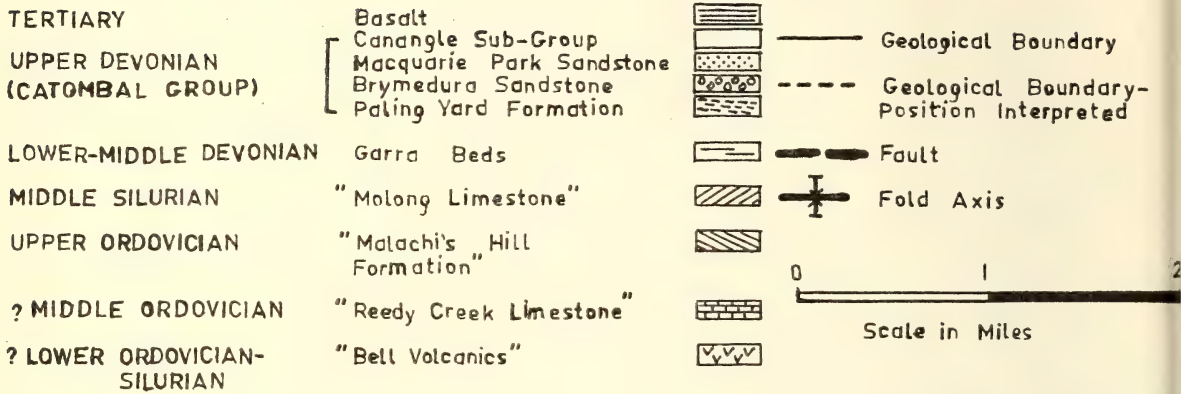


FIG. 14 (continued opposite)

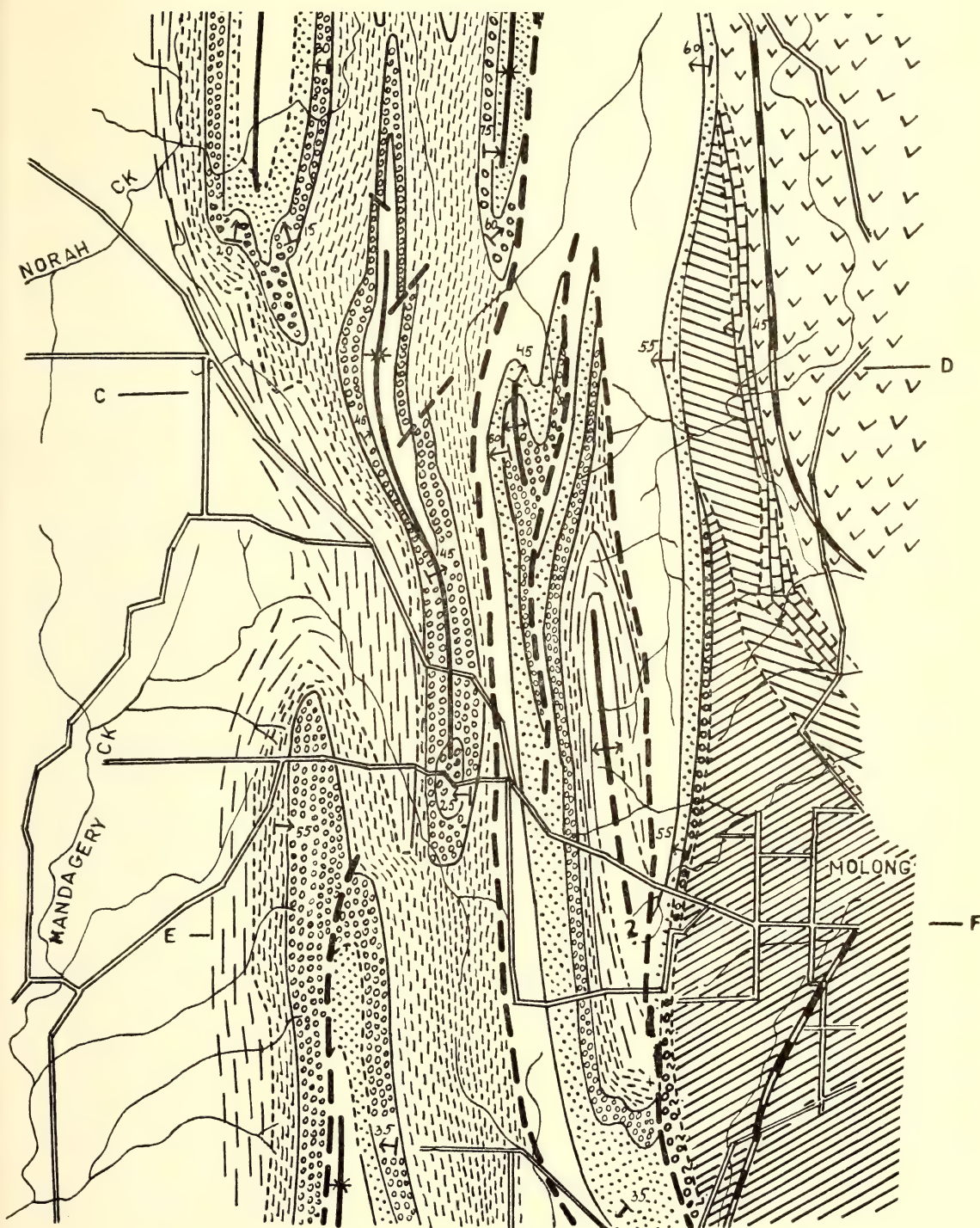
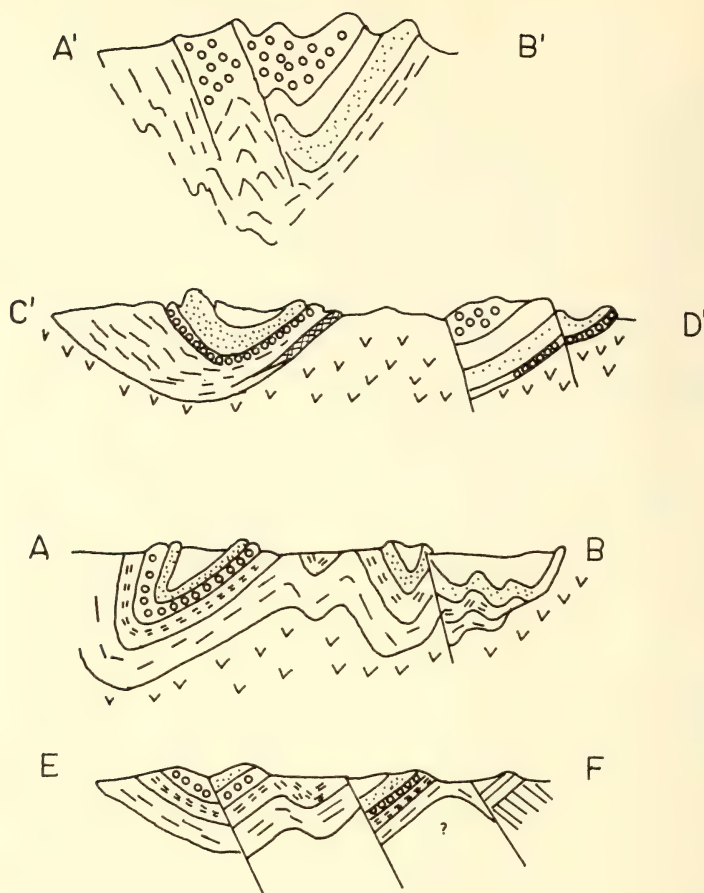


FIG. 14 (continued)



STRUCTURE SECTIONS OF GEOLOGICAL MAPS

SECTIONS A'B' AND C'D' FROM THE WELLINGTON REGION AND AB AND EF FROM THE LARRAS LEE - MOLONG REGION. (VERTICAL SCALE APPROXIMATE AND EXAGGERATED.)

FIG. 15

However, the conglomerates probably thin to the south and south-east from Wellington and received the bulk of their detritus from the west.

Recent investigations of a northerly extension of the Upper Devonian sediments preserved at Mt. Lambie (R. Mackay, personal communication) indicate that a similar succession to the Catombal Group exists to the south-west of Mudgee. This succession has an initial marine phase with preservation of brachiopods belonging to the genus *Cyrtospirifer*. This first phase is then followed by a "red bed" facies with preservation of many hundreds of feet of

conglomerate. It is possible that the sediments of the Mudgee-Mt. Lambie region and the sediments of the Molong-Wellington region were deposited in the same basin.

Further west of the Wellington-Molong region another large belt of Upper Devonian sediments outcrops from just east of Peak Hill southwards to Grenfell. These sediments have no definite basal marine and top terrestrial phases nor have any definite marine fossils been found. Instead fish plates (Hills, 1932) are relatively common alongside with *Lepidodendron* plant remains.

In most cases the basal sediments are thin arkoses or their equivalent. On top of the thin

basal terrestrial facies was laid a "rhythmic" sequence of red and white sandstones with finer red siltstones. This suggests that it is possible that the Peak Hill-Grenfell belt of Upper Devonian sediments is an inland facies of the Catombal Group.

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Explanation of Plates

PLATE I

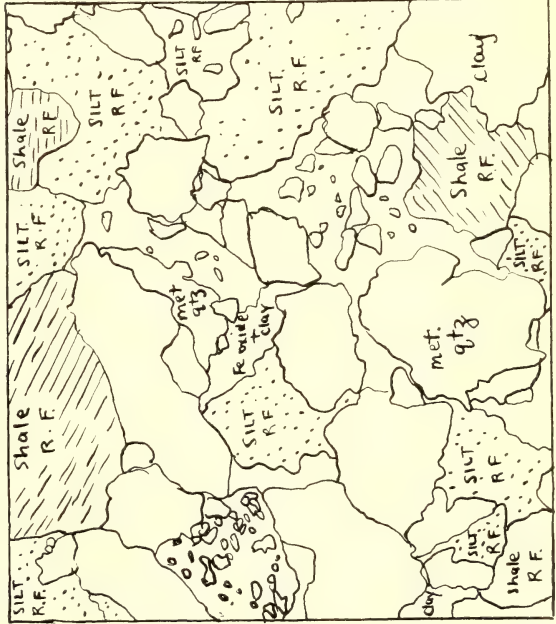
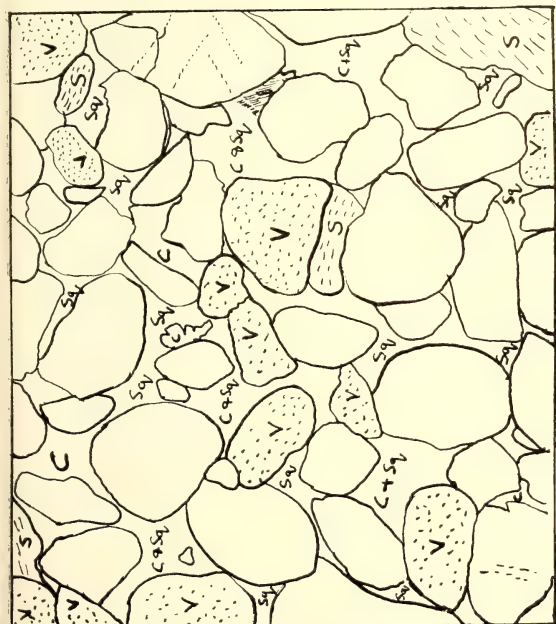
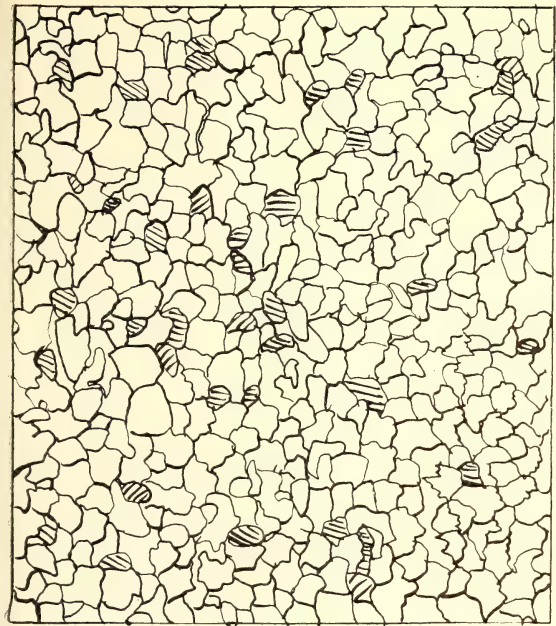
1. Line diagram of a well sorted coarse protoquartzite typical of the Brymedura Sandstone. Note the perfect rounding of both detrital quartz and volcanic rock fragments (*V*). [Pore space is filled with a mixture of clay and secondary quartz (*c+sq*) or secondary quartz outgrowth alone (*sq*).] In this sample volcanic rock fragments are more abundant than sedimentary rock fragments (*S*)
2. Line diagram of a typical well sorted Macquarie Park sandstone. Darker (lined) grains represent rock fragments which are scattered amongst an interlocking mosaic of quartz grains. Sutured contacts between grains and secondary quartz outgrowths can occur almost side by side, producing a very hard sedimentary "quartzite"
3. Line diagram of a sandstone typical of the top of the Kurrool Formation. This type of sandstone also occurs within the Curra Creek Conglomerate. Quartz grains are subangular, sorting is poor, and there is a relatively high percentage of matrix which contains scattered patches of iron oxide. Sedimentary rock fragments are common, both siltstone and shale types occur, probably derived due to reworking of earlier deposited fine sediments of the Catombal Group.
4. Line diagram of a lithic sandstone characteristic of the topmost Curra Creek Conglomerate. Grains are subangular and sorting is moderate. The matrix consists of silt and clay mixtures with many "squeezed" shale fragments

PLATE II

1. A large acid volcanic rock fragment showing rhyolitic flow structure. Brymedura Sandstone. Ordinary light. $\times 80$
2. Detrital quartz with sutured contacts (*s*) and interstitial clay matrix (*m*). One grain of quartz of metamorphic origin (*mq*). Macquarie Park Sandstone. Crossed nicols. $\times 100$
3. Lithic sandstone in the Curra Creek Conglomerate. Note abundance of Siltstone (*Si*) and Shale (*Sh*) rock fragments. Note the subangular nature of the quartz grains and the single grain of quartz of metamorphic origin (*mq*). Crossed nicols. $\times 40$
4. Coarse lithic sandstone from the Curra Creek Conglomerate. Note poor sorting, subangular quartz, metamorphic polycrystalline quartz, siltstone and shale rock fragments and the dark iron oxide and clay matrix. Crossed nicols. $\times 40$

PLATE III

1. Lithic sandstone, from the Brymedura Sandstone, the Gap, Larras Lee. Well rounded to subrounded detrital quartz and rock fragments of two varieties, volcanic (*V*), and sedimentary (*S*) and cemented by secondary quartz. Crossed nicols. $\times 25$
2. Rounded quartz grains cemented by secondary outgrowth of quartz. One grain shows a sutured break (*S*), secondary quartz outgrowth (*S.Qtz*) has occurred later than suturing. Brymedura Sandstone. Crossed nicols. $\times 60$
3. Protoquartzite with available pore space filled with secondary quartz (*S*). Detrital grain outlines are well rounded with tangential contacts. Note, several grains of polycrystalline quartz of metamorphic origin (*mq*). Brymedura Sandstone. Crossed nicols. $\times 40$
4. Calcilithite showing a large irregular limestone fragment surrounded on one side by a matrix of silt size quartz and iron stained carbonate and clay. Curra Creek Conglomerate. Ordinary light. $\times 30$



Geology of Lord Howe Island

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ABSTRACT—Lord Howe Island is composed of alkaline olivine basalt and aeolian calcarenite and is located on top of a large wave-cut platform, which is many times larger than the island. The platform was formed by wave action during the eustatic change in sea level associated with Pleistocene glaciation. The coral reef located on the west side of the island formed on top of the wave-cut platform and is therefore of Pleistocene to Recent age. A geological map of Lord Howe Island and a bathymetric map of the ocean surrounding Lord Howe Island were compiled and are included.

Introduction

Lord Howe Island is located in the southwest Pacific Ocean 436 miles northeast of Sydney, Australia, and 970 miles northwest of Auckland, New Zealand, at a latitude of $31^{\circ} 33'$ South and a longitude of $159^{\circ} 03'$ East. The island is perhaps best known for the large number of endemic species of plants and animals which exist there. Pope (1959) and Paramonov (1958, 1960) give good description of the biological aspect of the island. Except for the work of Etheridge (1889), little has ever been written on the geology of the island.

Most early geologists believed that the Australian continent extended eastward to the present volcanically active circum-Pacific belt and included Lord Howe Island, New Zealand, New Caledonia, Fiji Islands, and all of the area in between. This idea persisted for many years until the work of Officer (1955), Eiby (1958), and Standard (1961) showed that this is not the case and that Lord Howe Island is separated from the Australian continent by the Tasman Basin, which has a thin, 5 km, ocean basin type crust.

Recent oceanographic work by the Royal Australian Navy made it possible to construct a detailed bathymetric map, based on continuous echo sounding profiles, of the Lord Howe Island and Ball's Pyramid area (Fig. 1).

Recent aerial photography of the island reveals several discrepancies in the basic shape of the island as shown on the existing maps of Lord Howe Island, especially in the North Ridge area, the Coral Reef, and the coastal area northeast of Mt. Lidgbird. A geological map of the island using aerial photography as a base to correct these discrepancies has been prepared by the writer (Fig. 2).

Oceanography

Lord Howe Rise which is located between the Tasman Basin to the west and New Caledonia Basin to the east (Brodie, 1958) is a major physiographic feature of the southwest Pacific area. It joins the Coral Sea Platform in the north and the South Island of New Zealand in the south, and it is 100-200 miles wide. The average depth of the top of the Rise is about 700 fathoms compared with the 2,600 fathoms of the abyssal plain of the Tasman Basin.

Lord Howe Rise which was probably formed during the Lower Palaeozoic by orogenic growth on a thin ocean type crust, has a crustal thickness of 15-20 km.

Thomson and Evison (1962) state that New Zealand has a continental type crust 30-40 kms thick and point out that the work of Officer (1955) and Eiby (1957), who gave a crustal thickness of about 20 kms, applied only to the Wellington area and that their results were not reliable without further experiments.

Adams (1962) gives a 20 km crustal thickness to the Campbell Plateau southeast of New Zealand and Brodie (1952) considers the Campbell Plateau to be the southeastern extension of Lord Howe Rise which has been offset by faulting.

Kingma (1959) and Standard (1961) consider Lord Howe Rise to be a continuation of the structure of the northwestern part of the South Island. In view of recent findings it is possible that the 20 km crustal thickness of Lord Howe Rise and Campbell Plateau are related and that the thickening of the crust under New Zealand to that of a continental type occurred after the formation of Lord Howe Rise and Campbell Plateau.

Lord Howe Island is located near the western edge of Lord Howe Rise, but is separated from the main part of the Rise by over 1,000 fathoms of water.

The bathymetric map (Fig. 1) shows that Lord Howe Island, which is 1 mile wide and 6 miles long, is situated near the western edge of a large wave-cut platform (Fig. 3) which is 14 miles wide and 20 miles long. Ball's Pyramid, which is 0.2 mile wide and 1,811 feet high (Fig. 4), is an erosional remnant 12 miles south of Lord Howe Island and it is also located on a wave-cut platform 9 miles wide and 11 miles long. These two platforms are separated from each other by over 2,100 feet of water and were probably never connected even though they are both part of a much larger base (Fig. 3).

Deitz and Menard (1951) have stated that maximum effective depth of wave action is about 50 feet. Flint (1957) estimates that the maximum drop of sea level during Pleistocene glaciation was about 300 feet (50 fathoms). The platforms which surround Lord Howe Island and Ball's Pyramid are located at a depth of 50 fathoms (300 feet) and they are considered to have been formed by wave action during the eustatic change of sea level associated with Pleistocene glaciation.

Eventually these islands will be completely eroded away leaving guyots similar to those found in the Tasman Basin between Lord Howe Island and the Australian mainland (Standard, 1961).

The circulation of the warm Southeast Australian Ocean Current, which originates as a branch of the South Equatorial Current (Wyrтки, 1960) has caused a coral reef to grow on top of a wave-cut platform; this is the furthest south that a true coral reef has been recorded.

Physiography

The island may be divided into the following physiographic units:

1. The volcanic mountains—Mt. Gower and Mt. Lidgbird
2. The volcanic hills—North Ridge, Transit Hill and Intermediate Hill
3. The flat lying areas of sedimentary rock and alluvial material
4. The lagoon
5. The coral reef.

The volcanic peaks of Mt. Gower and Mt. Lidgbird which are 2,838 feet and 2,504 feet in elevation respectively, occupy the southern

half of the island and form the extremely rough mountainous terrain which dominates the view from all parts of the island (Fig. 5).

The younger volcanic hills of North Ridge, Transit Hill and Intermediate Hill range in elevation from 412 feet to 845 feet and form the low rounded hills which separate the flat lying areas (Fig. 6).

The flat lying areas of sedimentary rock are generally less than 100 feet in elevation, but they reach a maximum elevation of 250 feet on the north slope of Transit Hill. The flat lying areas which comprise less than 25% of the island are the only areas that are flat enough for habitation.

The lagoon, which is located on the west side of the island, is extremely shallow and, except for Comets Hole which has a depth of 23 feet, is generally less than 3 feet in depth at maximum low tide (Table 1) (Figs. 7, 8). Rabbit Island, which is part of a lava flow from Transit Hill, rises out of the lagoon to an elevation of 110 feet.

TABLE 1
Tidal Range—Lord Howe Island

6.972'	Indian spring high water
6.273'	Mean high water springs
5.741'	Mean high water
5.209'	Mean high water neaps
4.22'	(Old M.S.L. value. Datum for spot heights)
3.806'	Mean sea level
2.403'	Mean low water neaps
1.871'	Mean low water
1.339'	Mean low water springs
0.64'	Indian spring low water
00'	Datum of tide gauge

The Coral Reef which is bounded on the east by the shallow water of the lagoon drops off steeply on the west to a depth of over 60 feet.

Volcanic Rocks

The volcanic rocks of the island can be divided into two groups:

(1) The older Mt. Lidgbird volcanics, which make up a bulk of the island and form the two high mountain peaks at the south end of the island and Ball's Pyramid. These rocks probably rise from the floor of the ocean which is located at a depth of about 9,600 feet.

(2) The younger North Ridge volcanics which comprise the lower lying hills in the central and northern parts of the island and the Admiralty Islands northeast of the island.

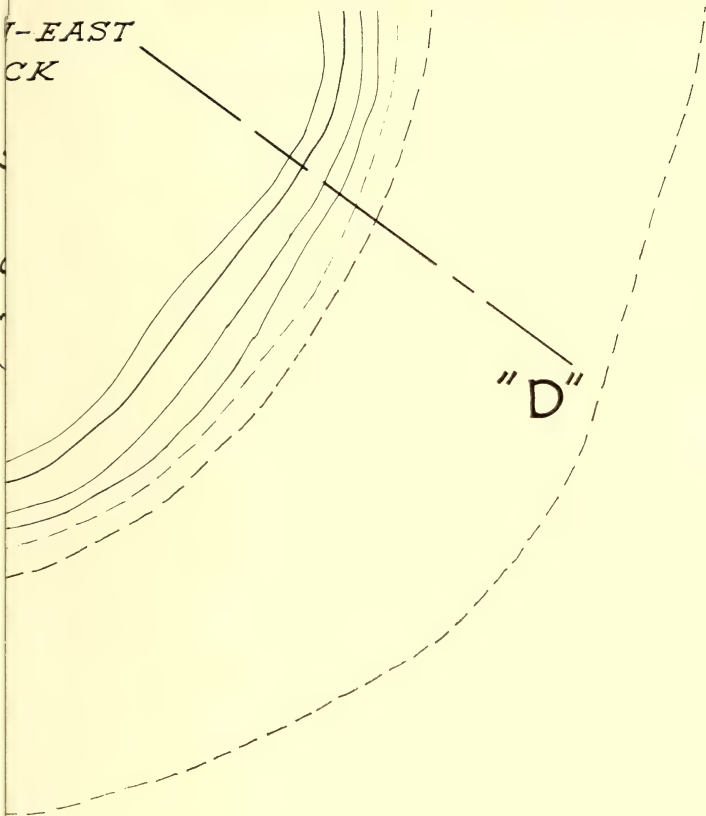
The average rock type of both is nearly identical being alkali olivine basalt, however

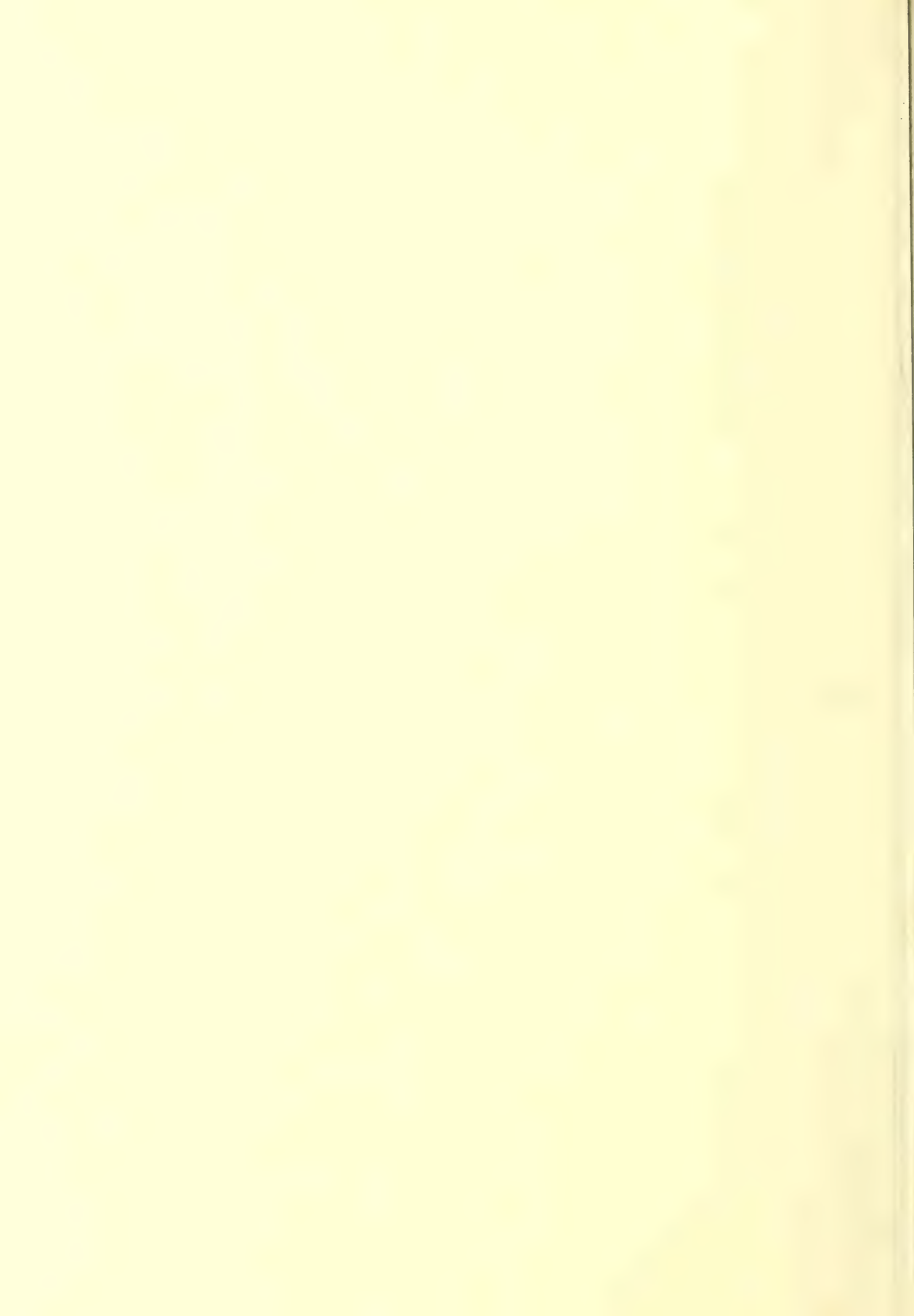


YMETRIC MAP

7-EAST
CK

"D"







BATHYMETRIC MAP OF LORD HOWE ISLAND AND BALL'S PYRAMID

1 0 1 2 3 4
Nautical Miles

"A"

"C"

"B"

LORD HOWE
ISLAND

OBSERVATORY
ROCK
WHEATSHEAF ID.

BALL'S PYRAMID

SOUTH-EAST
ROCK

"D"

Source of soundings: Royal Australian Navy
British Admiralty Chart N°350
Contour Interval: 10-20-50-100; then 100 fathoms intervals
Coral Reef
Position Inferred
• 2838' Land heights in feet





GEOLOGICAL MAP OF LORD HOWE ISLAND

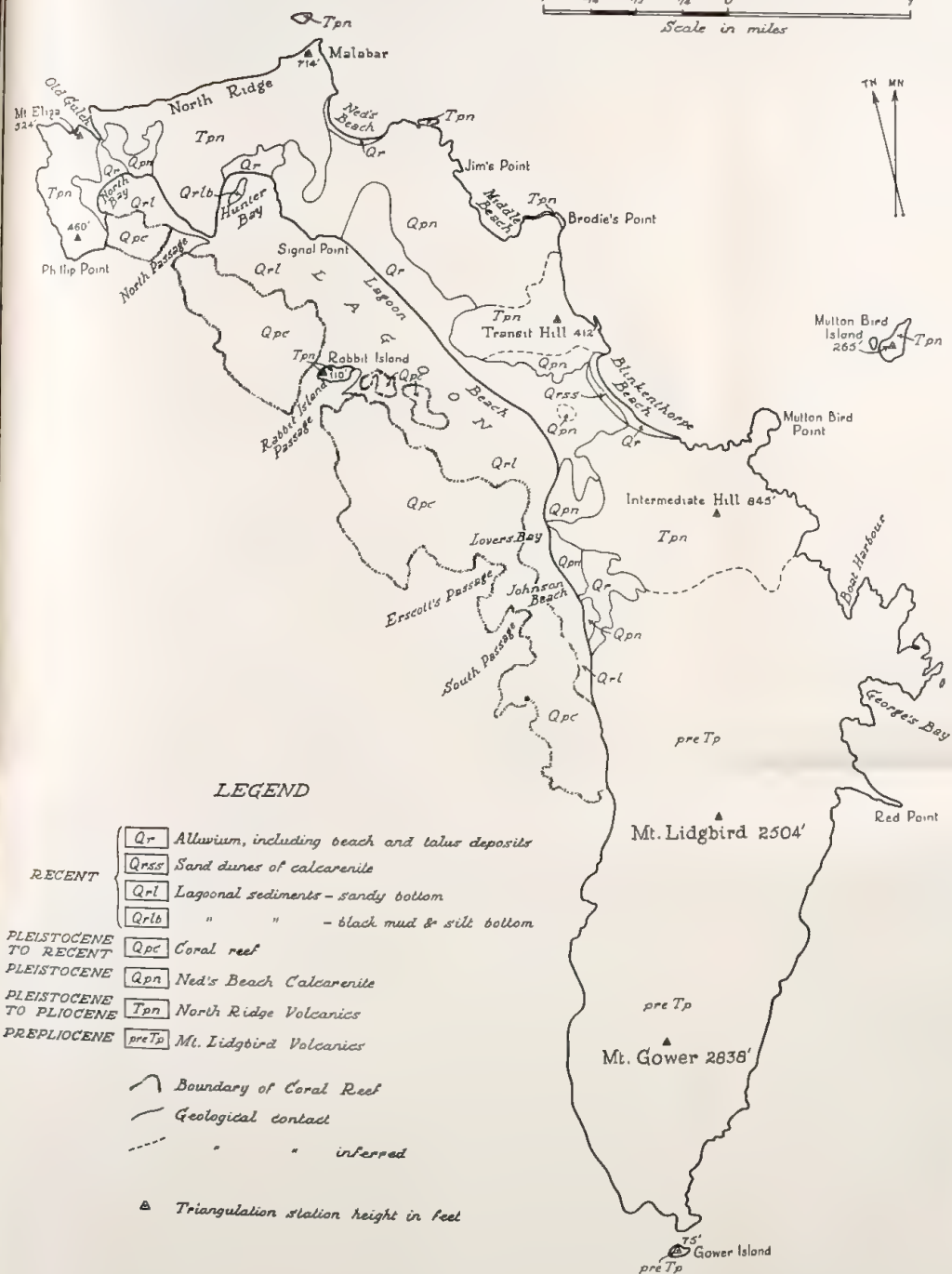
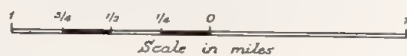


FIG. 2
Geological map of Lord Howe Island

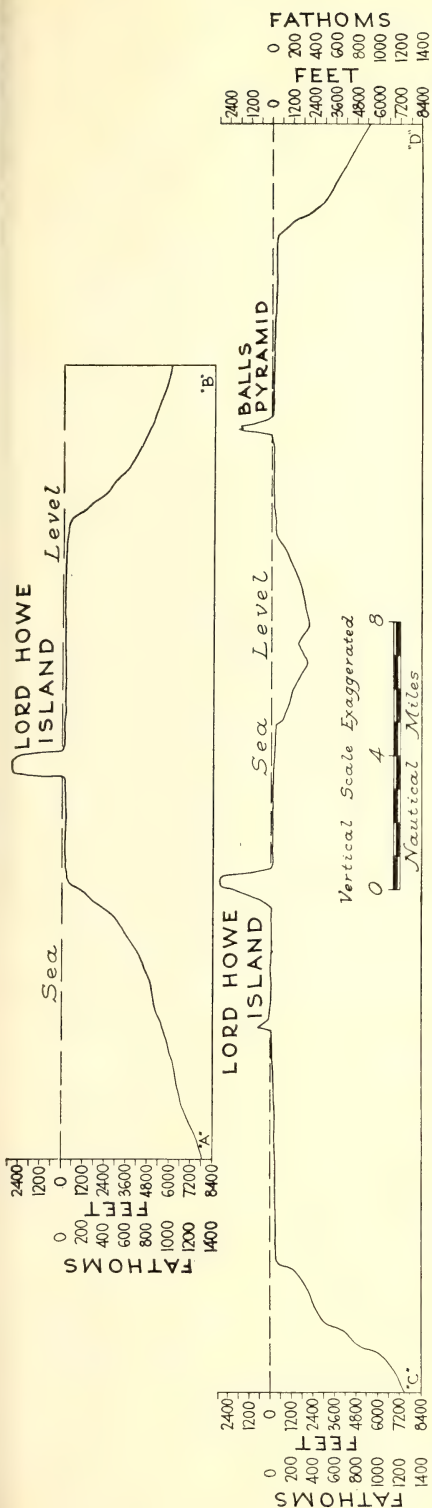


FIG. 3

East-west profile of the Lord Howe Island and north-south profile of Lord Howe Island and Ball's Pyramid

the older Mt. Lidgbird volcanics contain a much higher percentage of olivine rich rocks, oceanites or rocks approaching oceanites. Twelve of the 47 specimens of the older Mt. Lidgbird volcanics were olivine rich while only one of the 71 specimens of younger North Ridge volcanic rocks was olivine rich. The older rocks are generally coarser grained and also contain a



FIG. 4

Ball's Pyramid 12 miles south of Lord Howe Island, this erosional remnant rises to a height of 1,811 feet and is located on top of a large wave-cut platform which is 11 miles long and 9 miles wide

much higher percentage of zeolites than do the younger rocks whose cavities are generally open or filled with clay and/or carbonates.

MT. LIDGBIRD VOLCANICS

Mt. Gower and Mt. Lidgbird when viewed from a distance (Fig. 5) appear to be composed of flat lying sedimentary rocks, this layered effect being caused by series of nearly horizontal layers of igneous rock which range in thickness from a few feet up to 40 feet.

Flows: Dominantly alkali olivine basalt with phenocrysts of olivine, plagioclase and diopsidic clinopyroxene phenocrysts in an intergranular or intersertal groundmass of plagioclase, olivine and diopsidic clinopyroxene, magnetite, and ilmenite. Many of the basalts are very rich in olivine and contain deformed olivine grains and spongy clinopyroxenes. A few small peridotite xenoliths were found which Wilshire and Binns (1961) consider of mantle origin.

Dykes: Alkali olivine basalts. Altered olivine phenocrysts, plagioclase and diopsidic clinopyroxene phenocrysts in intergranular or intersertal groundmass composed of plagioclase, olivine, diopsidic clinopyroxene, magnetite and ilmenite.

The age of Mt. Lidgbird volcanics, which will also be the age of Lord Howe Island, is unknown, but they are considered to be early Tertiary. Paleomagnetic results from a rock sample from Mt. Lidgbird indicate a pre-Tertiary age (G. A. Dickson, personal communication). It is realized that no conclusion can be drawn from a single sample, but this perhaps gives some indication of age.

NORTH RIDGE VOLCANICS

These rocks which are much younger in age than Mt. Lidgbird volcanics contain some pyroclastic scoria and ash beds. Remnant flow structures, which give the flows a very recent appearance, are locally found in the basalts.

No definite age can be given to the North Ridge volcanics, but in one location, east of Old Gulch, at the northern end of the island, the calcarenite, which is considered Pleistocene in age, has been tilted and broken and much of the calcareous material has been dissolved and redeposited as travertine. This indicates that there has been some volcanic activity, or at least some hydrothermal activity, since deposition of calcarenite.

An attempt has been made to date the North Ridge volcanics on a geomorphological or

erosional basis such as has been done on the North Island in New Zealand (Kear, 1959). While it is realized that the rate of erosion due to climatic conditions may not be exactly the same for Lord Howe Island and the North Island of New Zealand still the two areas are similar enough that the Pliocene to Pleistocene age indicated by this method appears reasonable.

Flows: Dominantly alkali olivine basalts with phenocrysts of olivine, plagioclase and diopsidic clinopyroxene phenocrysts, the proportion of the three is extremely variable, in an intergranular or intersertal groundmass of plagioclase, olivine, diopsidic clinopyroxene, magnetite and ilmenite. Most are fine grained, many are glassy. Those with the coarser groundmass become doloritic with development of subophitic pyroxene-plagioclase intergrowths. A few basalts contain little or no olivine. Vesicles are commonly open or filled with clay and/or carbonate material.

Dykes: Alkali olivine basalts. Altered olivine phenocrysts, replaced by clay and carbonate or occasionally with epidote, quartz and tremolite (?), plagioclase and diopsidic clinopyroxene phenocrysts in intergranular groundmass composed of plagioclase, olivine, diopsidic clinopyroxene, magnetite and ilmenite.

Pyroclastic rocks: These consist entirely of fragments of glassy vesicular olivine basalt which may range in size from less than 2 mm to greater than 1½ inches and which are cemented with clay or carbonate. A single fragment of sanidine trachyte was found in one rock, this being the only non-basaltic rock found.

Sedimentary Rocks

All of the sedimentary rocks of Lord Howe Island are Pleistocene or Recent in age.

NED'S BEACH CALCARENITE

The calcarenite which forms the bulk of the sedimentary rocks on the island is composed almost entirely of calcium carbonate. The most widespread occurrence of calcarenite is found behind Ned's Beach where a ridge, which is up to 150 feet in height, is composed almost entirely of calcarenite. The ridge slopes to the south and the calcarenite which is found in the lagoon near Signal Point is below sea level.

During the Pleistocene period when the sea level dropped 300 feet the size of the island was greatly increased and a broad flat wave-cut terrace up to 20 miles in diameter was exposed above sea level (Fig. 1). This wave-cut terrace



FIG. 5

View from North Ridge of older volcanic rocks of Mt. Lidgbird and Mt. Gower in distance behind lagoon. Rounded younger North Ridge volcanics of Intermediate Hill, upper left. Breakers behind Rabbit Island, central right, indicate position of coral reef. Rocks exposed in lagoon between land and Rabbit Island are calcarenite. Photo K. Gillett



FIG. 6

View of Lord Howe Island from the top of Mt. Gower. Older Mt. Lidgbird volcanics on the right. North Ridge volcanics in distance. The coral reef, which separates the shallow water of the lagoon from the ocean, can be traced by the waves breaking on it. Photo E. de Villa

supplied the calcareous material which was deposited by the wind around the base of the existing hills.

The calcarenite is composed largely of fragmental detritus from *Lithothamnion* (coralline algae or nullipore) and *Halimeda* with pulverized coral, foraminifera, fragmented mollusca shells, etc. comprising only a small portion of the total composition of the rock. Wolf and Warne (1961) tested several specimens of the *Lithothamnion* collected by the author and noted that they were high-magnesian calcite.

The calcarenite is a "sandstone" comprised of calcareous grains which when viewed from a distance looks very much like a typical cross-bedded quartz sandstone found on most continents (Fig. 9).

The calcarenite is aeolian in origin and vector analysis of the cross-bedding has indicated that the prominent direction of wind during time of deposition was south 10° east. On the southwestern portion of the island which was protected from the prevailing winds by the already existing North Ridge, Transit Hill, and Intermediate Hill the uniform direction of the wind was disturbed and on the lee side of the hills a greater diversification of direction of deposition of sand is noted (Fig. 9). The highest location at which calcarenite has been found is on the northeast slope of Transit Hill where outcrops are found at elevation of 250 feet, this indicates that sand dunes accumulated on the windward side of Transit Hill to a height of at least 250 feet above present sea level.

The calcarenite is extremely susceptible to subaerial weathering and most of the outcrops are "honeycombed" and contain up to 70% pore space (Fig. 10). Vertical "solution pipes" which are formed by downward percolation of ground water and which have walls of redeposited calcite up to several inches thick are common (Fig. 11). The effect of subaerial weathering stops abruptly at high water mark and a single rock which is honeycombed and extremely porous above high water mark may a few inches lower, beneath a high water mark, be very solid and without noticeable porosity.

At the north end of the island northeast of North Bay Beach several caves are found in the calcarenite. The largest of these is accessible only by a collapsed vertical "solution pipe" which is about 3 feet in diameter and 15-20 feet deep. The area of the caves is in the drainage of North Ridge and the ground water easily flows through the extremely permeable calcarenite until it reaches the underlying basalt; it then flows downward along the top of the

basalt to the lagoon. It is in the calcarenite above the basalt contact where the largest cave, which is several hundred feet in length, has been formed. It is quite unusual to see caves formed in highly cross-bedded "sandstone" though occasionally the more typical cave appearance is found in the areas where stalactites and stalagmites are formed.

Several periods of deposition are noted in the calcarenite deposits which are separated from one another by soil accumulation of several feet (Fig. 12). These soil horizons, which commonly contain fossils of bird bones and of the land snail *Placostylus vibaricosus*, have been found in elevation ranging from 8 feet to 65 feet.

SAND DUNES

The only sand dune on the island is found behind the Blinkenthorpe Beach. This dune which is approximately 300 feet long and 80 feet wide is about 30 feet high and contains calcareous sand grains that have been blown by the prevailing westward winds from Blinkenthorpe Beach. The steeper lee side of the dune faces east towards the lagoon. The dune is composed of much the same material as the calcarenite and the beach sand, but the grain size is somewhat smaller than the beach sand.

CORAL REEF

The coral reef which is found on the west side of the island is the furthest south that a true coral reef has been recorded. This reef has grown on top of a wave-cut platform, which was formed during the Pleistocene lowering of sea level and is therefore about 300 feet thick and of Pleistocene to Recent age. Coral growth is common on all sides of the island but only on the west side has a reef formed.

Probably because of colder water the coral reef and the shallow water around Lord Howe Island contain a much higher percentage of *Lithothamnion* than do the waters around Great Barrier Reef and the cementation by the *Lithothamnion* is perhaps more important to the formation of the reef than that of the coral itself. *Lithothamnion* growth is especially noticeable at extreme low tide in the southern part of the lagoon at Lover's Bay and Johnson's Beach where large areas are covered with a pinkish mauve carpet of *Lithothamnion* which in places form pools that resemble terraced pools such as those found in thermal springs areas (Fig. 13). These pools, which are about 2-3 feet wide and up to a foot in depth are surrounded by rims of *Lithothamnion* and *Lithothamnion* precipitated CaCO_3 .

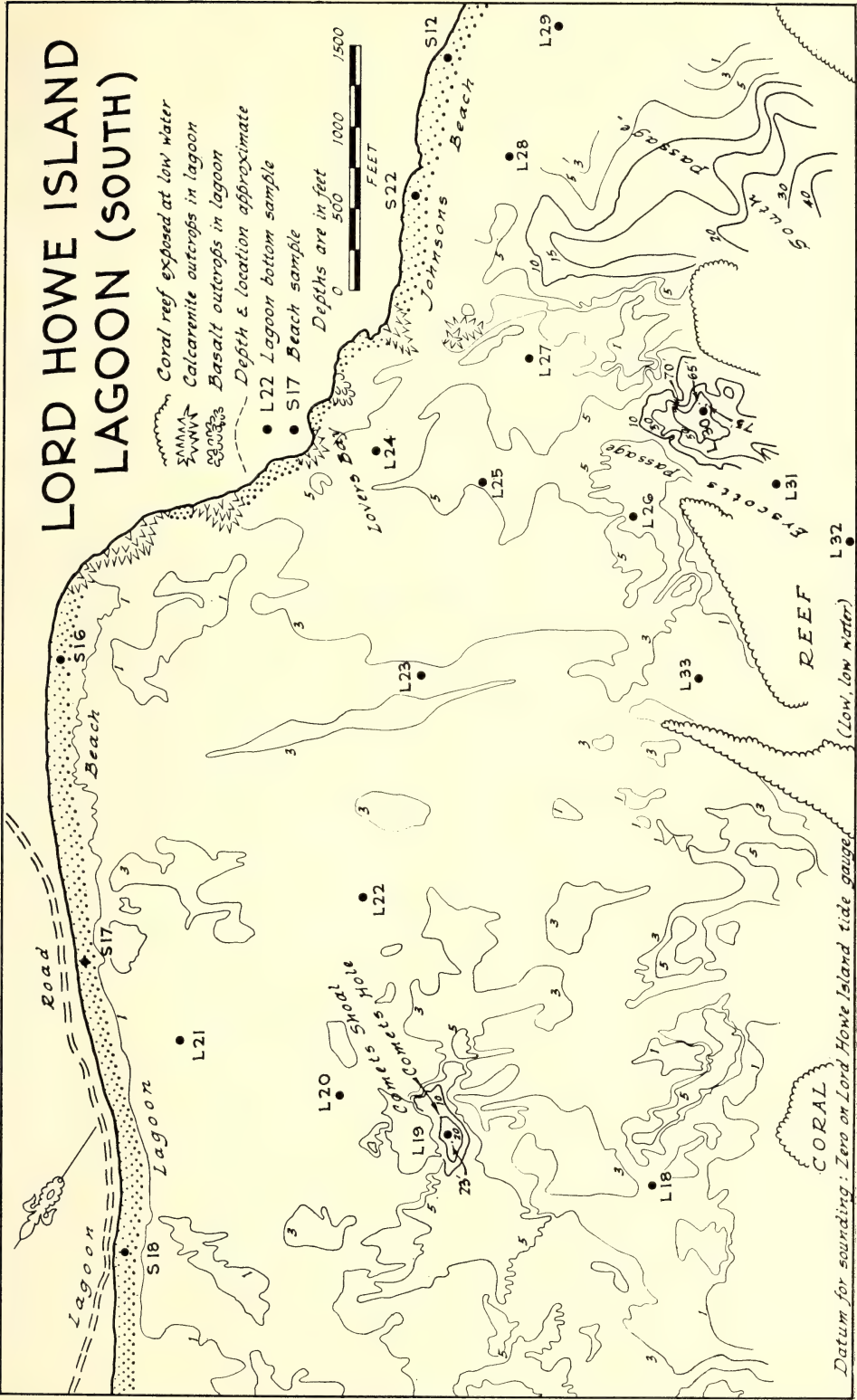


FIG. 8
Map of Lord Howe Island Lagoon (south)

The coral reef almost completely blocks the lagoon with only three passages existing that are suitable for boats' passage (Figs. 7, 8). The North Passage, which is about 40 feet deep, Rabbit Island Passage which is about 30 feet deep, and Erscott's Passage which is about 75 feet deep. These passages are very narrow and much of the large volume of water that covers the reef and fills the lagoon at high tide must pass out through these openings as the tide recedes. This produces very strong rip currents in these passages as the tide lowers and this has an effect upon the distribution and shape of the coral growth within the lagoon. The coral polyps have arranged themselves in an arch-like pattern parallel to the flow of the strongest current (Fig. 14).

The coral reef acts as a breaker for storm waves that might have otherwise cut the island in half at its narrowest point, between the lagoon and Blinkenthorpe Beach, and have eroded away much of the alluvial material and much of the calcarenite.

Probably because of the colder water the underwater scenery of Lord Howe Island is quite different from that of the Great Barrier Reef. Most of the Lord Howe Island reef is made up of massive type corals such as the *Acropora brueggermanni* and *Gonianstrea benhami*. The fine branching types of coral such as the staghorn coral *Acropora pulchra* so commonly found on the Great Barrier Reef are almost completely missing. Much of the associated reef life, especially the mollusca, are much smaller and the amount of algae and seaweed growth is much greater.

In the deeper waters, 60 to 100 feet, on the sea-side of the reef no sandy material was noted, the bottom being covered by large coral boulders and living coral growth which formed a very rugged topography with many large overhanging ledges, caves and steep walled "gullies".

The tidal fluctuation of Lord Howe Island is about 10 feet and except for the passages most of the reef is exposed at low tide. The top of the reef has been bevelled by wave action and is covered by dead coral; living coral is rarely found above the low tide level (Table 1).

LAGOON SEDIMENTS

The lagoon is extremely shallow, being an average of only about 3 feet deep at maximum low tide (Figs. 7, 8).

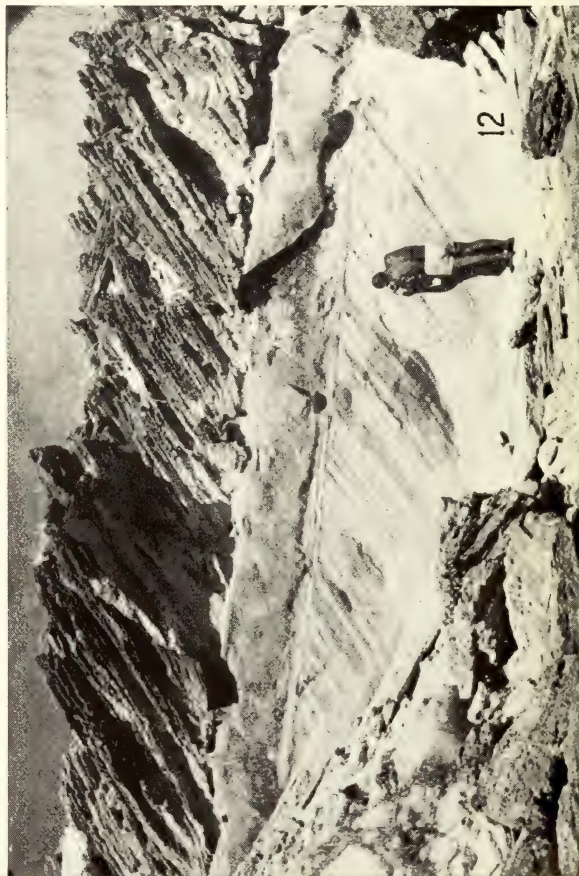
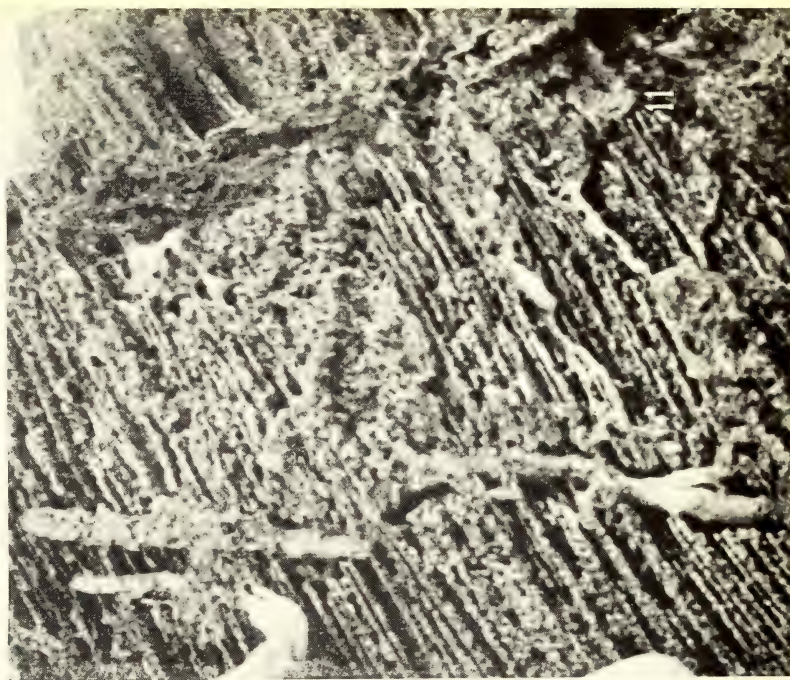
Sandy bottom: The floor of almost the entire lagoon is covered with calcareous sand that except for the coarser grainsize is basically the

Fig. 11.—Vertical "solution pipes" of redeposited calcium carbonate developed in highly cross-bedded calcarenite

Fig. 12.—Soil horizon, $3\frac{1}{2}$ feet thick, developed between two layers of cross-bedded aeolian calcarenite. The direction of deposition of both upper and lower beds of calcarenite is identical

Fig. 9.—Highly cross-bedded calcarenite near Johnson's Beach

Fig. 10.—"Honeycomb" weathering developed in calcarenite, Middle Beach. Note two-shilling coin for scale



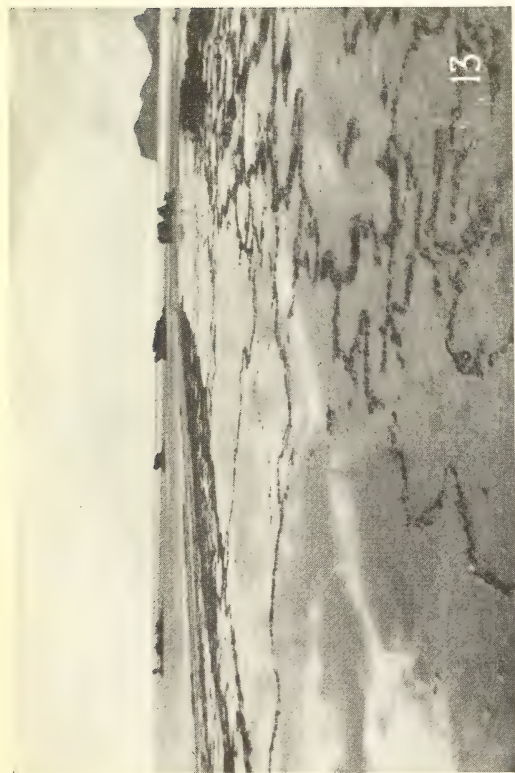


FIG. 13.—*Lithothamnion* pools developed at low tide, remnants of calcarenite rising from the floor of the lagoon in the background



FIG. 14.—Concentric growth of coral in the lagoon viewed from Transit Hill. This unusual shape of coral growth is believed to be caused by the strong flow of the currents, during lowering of the tide, towards Fremont's Passages located at the left of the photo. Due to the tide



FIG. 15.—*Lithothamnion* cemented "recent conglomerates" composed of pebbles of volcanic rocks. Rounded hills of North Ridge volcanics in background beyond lagoon



FIG. 16.—Vertical aerial photo of an isolated pool with a black mud bottom near beach in Hunter's Bay. The shallow bottom of the lagoon is covered with sand and occasional scattered growths of coral. Many of the dark spots on the left are tufts of green marine grass. Length

same composition as the calcarenite, being composed primarily of coralline algae and *Halimeda* material with pulverized coral mollusc shells and foraminifera, etc. forming only a minor portion of the total material. The sand is much coarser near the beach in the area of wave action and becomes finer both landward and seaward.

Detailed samples of the entire lagoon reveal little change in composition except that in the deeper, 40 to 70 feet, and faster moving water of the passages there is little sand size material and most of the bottom is covered with broken coral debris.

The following list of foraminifera have been identified by D. A. Belford, micropalaeontologist with the Bureau of Mineral Resources, from samples collected by the author. In the beach and lagoon samples little variation was noted in the species present, but a change in the frequency of occurrence of species was noted. The wind-deposited specimens from the calcarenite were poorly preserved.

Foraminifera identified in lagoon samples :

Hauerina ornatissima (Karrer)
Polysegmentina circinata (Brady)
Peneroplis planatus (Fichtel and Moll)
Sorites marginalis (Lamarck)
Marginopora vertebralis Quoy and Gaimard
Pavonina flabelliformis (d'Orbigny)
Sigmavirgulina tortuosa (Brady)
Lagena radiato-marginata Parker and Jones
Uvigerina porrecta Brady
Orbulina universa d'Orbigny
Globigerinoides ruber (d'Orbigny)
Globigerina subcretacea Lomnicki
Pulleniatina obliquiloculata (Parker and Jones)
Patellina corrugata Williamson
Epistomaroides polystomelloides (Parker and Jones)
Baculogypsina spherulata (Parker and Jones)
Tretomphalus bulloides (d'Orbigny)
Elphidium jenseni Cushman
E. poeyanum (d'Orbigny)
Quinqueloculina polygona d'Orbigny
Spiroloculina corrugata Cushman and Todd
Triloculina tricarinata d'Orbigny
Globigerina bulloides d'Orbigny
Reussella spinulosa (Reuss)
Conorbella patelliformis (Brady)
C. pyramidalis (Heron-Allen and Earland)
Triloculina irregularis (d'Orbigny)
Articulina pacifica Cushman
Buliminoides williamsoniana (Brady)
Siphoninoides echinatus (Brady)

Siphogenerina raphanus (Parker and Jones)
Cymbaloporella squamosa (d'Orbigny)
Discorbis rugosus (d'Orbigny)
Heterostegina suborbicularis d'Orbigny
Amphistegina madagascariensis d'Orbigny
Trifarina bradyi Cushman.

Foraminifera identified in beach samples :

Hauerina ornatissima
Polysegmentina circinata
Peneroplis planatus
Sorites marginalis
Marginopora vertebralis
Pavonina flabelliformis
Sigmavirgulina tortuosa
Uvigerina porrecta
Baculogypsina sphaerulata
Tretomphalus bulloides
Elphidium jenseni
E. poeyanum
Triloculina tricarinata
Spiroloculina corrugata
Conorbella patelliformis
C. pyramidalis
Buliminoides williamsoniana
Siphoninoides echinatus
Siphogenerina raphanus
Heterostegina suborbicularis
Amphistegina madagascariensis
A. radiata (Fichtel and Moll)
Anomalina maculosa Todd.

Foraminifera identified in land samples :

Amphistegina radiata
Elphidium jenseni.

At low tide in the southern part of the lagoon, near Lover's Bay, an unusual outcrop of "recent conglomerate" was noted (Fig. 15). This "recent conglomerate" is composed of sub-angular to sub-rounded fragments of igneous rocks which average about 3 inches in diameter. Upon first glance the rocks seem to be lying loose on the surface, but closer examination reveals that these rocks are completely cemented together by calcium carbonate which has been precipitated by *Lithothamnion*. Several rounded nodules up to 1 inch in diameter which were coated by lithothamnion material and which had nuclei of either igneous or sedimentary rocks were found.

Black mud : Located near the northern end of the lagoon, in Hunter Bay, there is an isolated pool of water which has a depth at maximum low tide of about 12 feet and which is surrounded by water only two feet deep (Fig. 16). Due to the reducing environment which exists

in this nonoxygenated body of water the bottom of this pool is covered with black mud. This mud is extremely high in sulphur content, the smell of H_2S being very noticeable. Small specks of syngenetic pyrite were noted in the samples collected in this location. In the 75-foot deep hole in Erscoth's Passage, which is beneath the level of the affect of tidal currents (Fig. 8), and in the sandy sediments a foot or so beneath the floor of the lagoon reducing conditions were also noted.

Possible Origin of Fauna and Flora of the Island

Paramonov (1959, 1960) entitled his paper on Lord Howe Island "Riddle of the Pacific". A large part of this riddle is connected with the fact that while Lord Howe Island is closer to Australia than to New Zealand a large number of plants and animals, many of which are not supposed to be able to travel over large distances of water, are more similar to New Zealand types than to Australian types.

If we consider the size and distribution of the islands that existed during the lowering of sea level, 300 feet, associated with Pleistocene glaciation this does not present such a great problem. An investigation of the British Admiralty Oceanographic Chart No. 780 reveals the presence of several sea mounts 320 miles northeast of North Island, New Zealand, which were exposed during the Pleistocene lowering of sea level.

These islands may have acted as stepping stones for New Zealand type fauna to migrate to both Lord Howe Island and Norfolk Island. With more detailed oceanographic soundings it is probable that other shallow sea mounts, which were islands during the lowering of the sea level associated with Pleistocene glaciation will be found along Lord Howe Rise and these islands may have also acted as stepping stones. Several specimens of an extinct turtle *Meiolania* have been found embedded in the calcarenite. Since the same species of turtle have been found in Australia, and since this turtle is thought to be a land turtle, previous workers, both biologists and geologists, erroneously concluded that Lord Howe Island and Australia were once connected. Recent geophysical and oceanographic work showed that no connection between Lord Howe Island and the Australian continent ever existed (Standard, 1961).

Evolution during the prolonged isolation before and since the Pleistocene has probably

been responsible for the development of the large number of endemic species found on the island. Many species, especially among the bird population, have become entirely extinct since the island was discovered in 1788. There is no record or indication that the Polynesians or any other race of man ever lived on the island prior to 1788.

Many other isolated islands throughout the Pacific probably had a similar number of endemic species prior to the coming of man. The rapid extinction of the weaker species probably occurred on many isolated islands, just as it did on Lord Howe Island, after the arrival of man but it was not recorded by the Polynesians or other native people who first settled the isolated islands.

Acknowledgements

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The History of Vulcanism in the Mullally District, New South Wales

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ABSTRACT—Deeply dissected remains of an extensive volcanic field in the Mullally District consist of dolerite, alkali basalt, and minor trachyte flows and pyroclastic rocks. These were deposited on a mature erosional surface on Permian sandstones and shales, and are separated from the main Warrumbungle volcanic field, with which they are comagmatic, by a relatively high ridge of sedimentary rocks at the western margin of the area. Many trachyte and phonolite bodies occur as dome intrusions in the sediments and overlying flows, and most are independent of conduits which fed surface eruptions. Two cryptovolcanic dome structures in the sedimentary rocks are attributed to unexposed acid intrusions. Petrographically, the rocks comprise a typical alkali basalt-trachyte-phonolite province, the basic members of which contain peridotite and gabbroic xenocrystal material. No specific order of eruption from acid to basic lavas was discovered.

Introduction

Mullally is located 23 miles southwest of Gunnedah on the Oxley Highway. The most prominent volcanic features, which often rise over 1,000 feet above the surrounding flat countryside, are located west and southwest of Mullally. Neither the state geological map of New South Wales (First Edition) nor a regional study encompassing the Mullally District (Dulhunty, 1940) recorded the abundant remnants of volcanic rocks in the area described (Fig. 1), although the major physiographic features are caused almost entirely by the volcanic rocks. Brief mention of the occurrence of basalt flows and trachyte intrusions in the area was made by Kenny (1928). An area of approximately 400 sq. mi. was mapped; mapping was done on 2 inches=1 mile aerial photographs and the information transferred to an uncontrolled aerial photographic mosaic of the same scale which served as the base map.

Geological Setting

Sedimentary rocks in the area are composed of interbedded quartz sandstones, conglomerates, and shales. Kenny (1928) considered the sediments to be of Lower Mesozoic age, and later Dulhunty (1940) referred to them as Jurassic. However, the occurrence of *Glossopteris* and other plant fossils in many shale

units indicates a Permian age. This age is the same as that found for sediments in the Warrumbungle Mts. (Jensen, 1907*a*) and in the Nandewar Mts. (Jensen, 1907*b*). The nature of the sediments suggests a flat, low-lying depositional environment.

The volcanic rocks are identical with those of Tertiary age in the Warrumbungle Mts. and actually are part of a nearly continuous belt of volcanic rocks between the Warrumbungle Mts. and Nandewar Mts. (Fig. 1). Kenny (1928, p. 118) considered the lavas to be interbedded

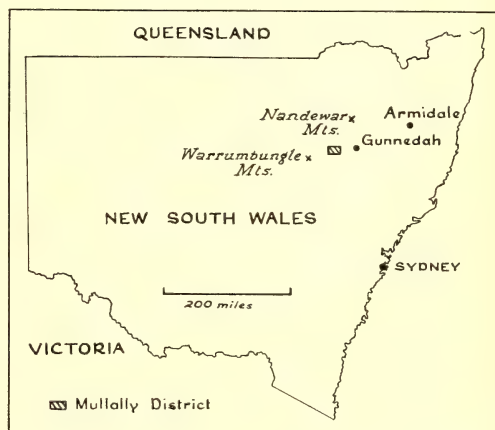


FIG. 1

Location map of the Mullally District, New South Wales

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with sediments of Lower Mesozoic age and that the trachyte plugs represent feeders to these lavas. Detailed mapping has shown this to be incorrect, and that the lava flows everywhere overlie the sediments. No definite evidence of the age of the volcanic rocks has been found, but similarity of these rocks to those of the Warrumbungle Mts. which are known to be Lower Tertiary (Jensen, 1908, p. 592), suggests the same age.

The physiography of the region during vulcanism was similar to that of the present sedimentary exposures which exhibit very mild relief with broad, shallow stream channels. This is evident from the distribution of the earliest lava flows. The absence of volcanic remnants on the relatively high ridge of sedimentary rocks at the western margin of the area suggests that this area was a physiographic high during vulcanism. Consequently, it is believed that the aggregate thickness of volcanic rocks to the east of this ridge was not great and that erosion has not removed more than a few hundred feet (possibly less than 200 feet) of volcanic rocks since their formation.

Evidence of block faulting accompanying vulcanism in the Warrumbungle Mts. (Jensen, 1907a) was not found in the Mullally District. The magnitude of dips recorded by Jensen in support of this suggestion is within the range of initial dips of cross-bedded units measured by the writers. Although subsequent erosion has considerably altered the original appearance of the terrain, it is likely that the area was covered by small coalescing cones, the largest of which was centred at Mt. Bulga (Fig. 2). This is suggested in part by the fact that most of the acid intrusions are not conduit fillings of volcanic cones but are rather isolated masses which penetrated and deformed the sediments in their presently observed sizes and forms; the tops of some are well below surrounding sediments and still others are not yet exposed.

Bedded Volcanic Rocks

In the northern part of the area, the first eruption formed an extensive dolerite flow ranging in thickness from 30 feet to more than 60 feet. No chilled margins were observed at the base of the flow and it is everywhere overlain by basalt. Although the coarse granularity of this rock is similar to that of nearby dolerite sills (see Wilkinson, 1958), it has evidently been erupted at the surface and filled in topographic lows of the old erosion surface. Inspection of Fig. 2 shows many places where overlying basalt flows overlap the edges of the dolerite

so that both rest on sedimentary rocks. Both basalt and dolerite dykes occur at stratigraphically lower levels than the flow which suggests that something other than rate of cooling has conditioned grain size and that granularity is not a reliable guide to intrusive emplacement. The location of feeders to the dolerite is not definitely known, but gentle dips of the lower contact with sediments away from Mt. Ruth (Fig. 2) suggest a location in this vicinity.

Accompanying the extrusion of basaltic lavas, which covered wide areas as relatively thin flows, was eruption of basaltic pyroclastics. Fragments of scoria are commonly found near the base of the basalts and rarely, as might be expected from the time available for erosion, small remnants of cinder cones are found. Several basalt intrusions of irregular form were found (Fig. 2), but from the extent of the basalt flows it seems likely that most were erupted from numerous, now buried, fissures.

In the southern part of the area trachyte and phonolite eruptions occur along with basalts, for they are locally interbedded and either may rest on the sediments over short distances. In the Mt. Bulga area, probably the only sizeable volcano in the district, the earliest eruptions consist mainly of trachyte pyroclastics (dominantly lapilli tuffs with some ash and breccia) with a few interbedded basalt flows. The younger Mt. Bulga Formation in most places stands out as a prominent ridge above the older pyroclastic rocks, and overlies the earlier basalt flows at the northernmost exposures. This unit consists dominantly of massive trachyte flows with some interbedded pyroclastic units. From their distribution, both the younger and older units were probably erupted from a crater now occupied by the Mt. Bulga phonolite dome. Among the latest eruptions are very small remnants of a remarkable porphyritic basalt (Twin Peaks type, Fig. 2). In nearby volcanic terrains it has been supposed that a consistent order of eruption from acid to basic lavas has occurred (Sussmilch and Jensen, 1909; Jensen, 1907a, 1907b; Browne, 1933). In the Mullally District such a generalization does not hold and no specific order of eruption was discovered.

Intrusive Rocks

Intrusions of basalt and dolerite are relatively uncommon and generally are of irregular shape. Two of the basalt intrusions may have been plugs, but others of similar shape occur well below the level of surrounding sediments and

Basalt

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are best referred to as small stocks rather than infillings of conduits which fed surface eruptions.

The same is true of the 34 trachyte and phonolite intrusions which are, with the exception of Mt. Bulga and possibly a few others, stocks or dome intrusions in sediments. Mt. Bulga is a dome intrusion within the lava sequence and, because there is no significant deformation of the bedded volcanic rocks, it is thought to have been injected into the main crater through which earlier trachytes were erupted. Elsewhere, where contact relations may be observed, the acid intrusions deform the surrounding sediments and have been intruded as masses independent of principal extrusive conduits or of conduits which were feeders to basic lavas. In one example (Ratz's Castle, Figs. 2, 3), the acid intrusion deformed both the sediments and overlying basalt flow and acid tuffs which stand out as prominent *cuestas* for $\frac{3}{8}$ mile from the intrusion. As the age relationships between such intrusions and the surrounding flows are so rarely determinable in New South Wales, a detailed map of Ratz's Castle is shown in Fig. 3*d*.

Two cryptovolcanic structures were observed (Fig. 2) and have the form of dome structures in the sediments. That these were produced by as yet unexposed intrusions is clear from the occurrence of three other similar structures (Fig. 3) which are locally breached by trachyte intrusions. Ratz's Castle represents a late stage in the dissection of such structures. Local breaching of the sedimentary dome structures also provided a clue to the cause of the unusual response of several intrusions to erosion. Some of the domes have topographically high margins and central depressions, while others are deeply incised by stream channels. This is believed to reflect an original irregular top of the intrusion as shown in Fig. 3.

Most of the acid intrusions have at least locally developed flow foliations expressed in alignment of tabular feldspar crystals, flow layers represented by concentrations of phenocrysts, and sheet joints parallel to flow foliations. These structures are best developed near the margins of intrusions and show dips between 30° and 80° towards the centre. Such structures strongly suggest a dome shape for the intrusions, a shape which is common in volcanic terrains (Williams, 1932). It is likely that the domes were fed by dykes and expanded to their present shape only when the magma approached very close to the surface of the sedimentary rocks or penetrated a thin cover of lavas.

Petrography

BASALT

All of the basalts, both intrusions and flows, are members of the alkali olivine basalt group and consist, in varying proportions, of olivine, titanite, plagioclase, and magnetite. Minor accessories include interstitial analcite, alkali feldspar, and apatite. Amygdules filled with clay or anisotropic zeolite are common. Olivine (average composition about Fo₈₀) is frequently partly altered to green clay which is readily oxidized to red clay by weathering. A preferred orientation of clay fibres or sheets in pseudomorphs represents structural control of origin olivine on its alteration product (see Brown and Stephens, 1959; Gay and LeMaitre, 1961), but many occurrences were noted in which fibres had random orientation. Olivine is the only common phenocryst in basalts and also occurs as anhedral to euhedral grains in the groundmass. Plagioclase (An₅₉₋₆₂) occurs most commonly as flow banded laths showing normal oscillatory zoning, while pyroxene and magnetite granules occupy interstitial spaces between plagioclase laths. Quartz xenocrysts with radial clinopyroxene coronas are common, and cognate basalt xenoliths are present in some flows and intrusions.

More than half of the basalts studied contain xenocrystal material of peridotite origin; in basalts which might otherwise be classed as limburgites, this material makes up a significant percentage of the rock. Peridotite xenoliths as such are rare and none larger than 2 inches in diameter was found. Xenoliths show the typical signs of solid deformation described by Wilshire and Binns (1961) which consist of deformation lamellae in olivine and orthopyroxene. Marginal reactions of the component minerals include normal zoning of olivine, incongruent melting of orthopyroxene to form granular coronas, and partial fusion of clinopyroxene to produce a spongy zone followed toward the host basalt by a newly precipitated salite rim. The fabric of some xenoliths is not strictly allotriomorphic-granular and some olivine grains have dome faces which dovetail with neighbouring olivine grains, while prismatic faces are sometimes developed adjacent to orthopyroxene grains. Both the deformational features shown by individual mineral grains and their characteristic reactions with the host rock were used to identify xenocrysts of the same origin. The occurrence in some rocks of subhedral olivine grains with deformation lamellae does not preclude an origin from peridotite as the same forms are found within

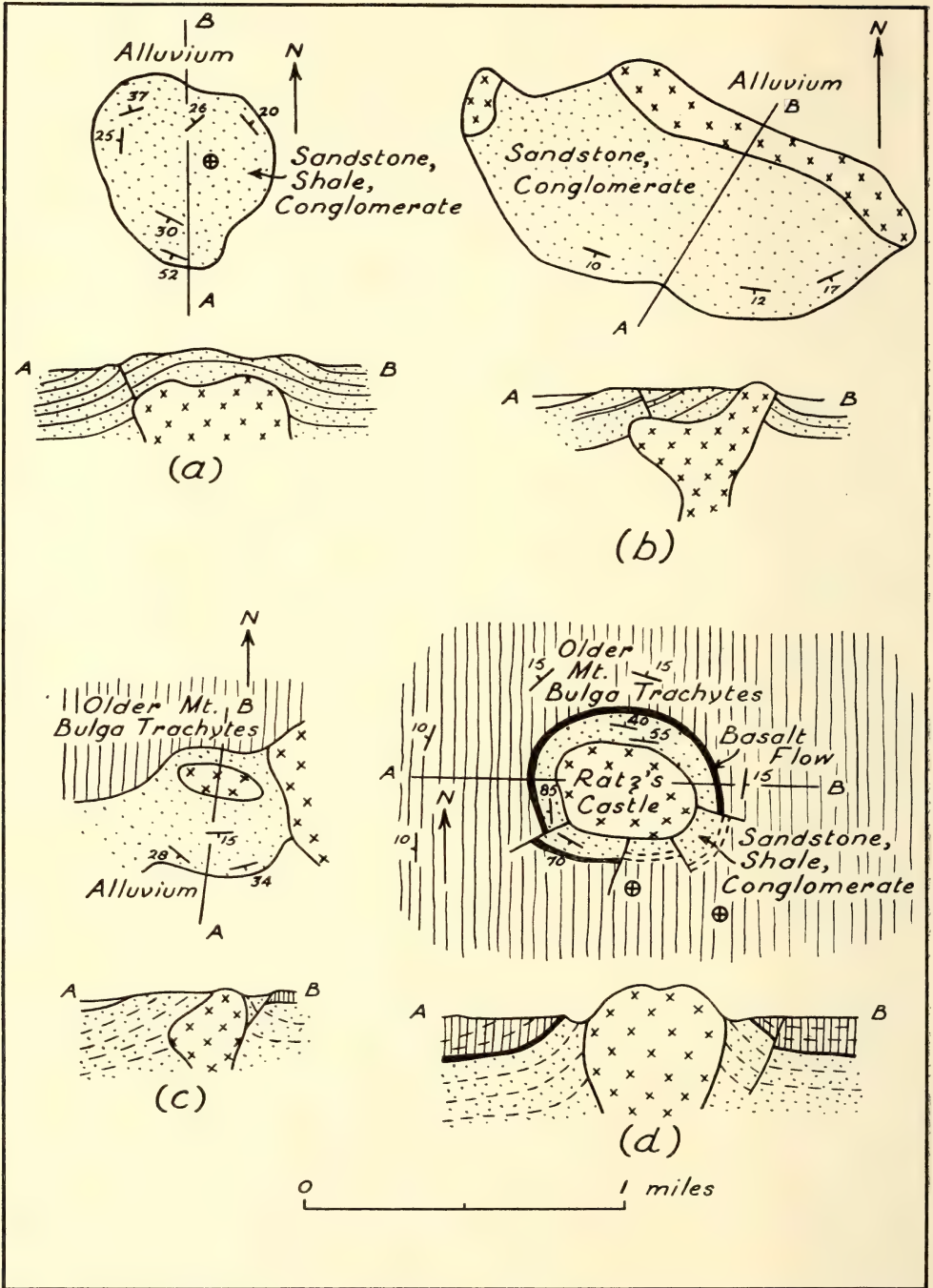


FIG. 3

Different stages of breaching of sedimentary dome structures by trachyte intrusions. (a) Cryptovolcanic structure, (b) partly breached structure, (c) early stage of development, (d) late stage of intrusion and dissection

peridotite xenoliths. The peridotite is considered to be of mantle origin, and not of cognate origin as suggested by Brothers (1960). Small gabbro fragments consisting of a few interlocking grains of very spongy clinopyroxene grains and plagioclase showing strong marginal resorption and reversed zoning are rare. Although no spinel was found in the small xenoliths, some basalts contain rounded grains of turbid green spinel with opaque reaction rims. Occasionally newly precipitated magnetite has produced serrate margins on spinel xenocrysts.

TWIN PEAKS BASALT

This rock type has a very distinctive appearance in hand specimen due to abundant clots of plagioclase, opaques, pyroxenes, and olivine. In thin section the host rock exclusive of large grains is seen to be olivine basalt not differing significantly from those described above. Large grains consist of spongy, anhedral clinopyroxenes which are often in aggregates of interlocking grains, plagioclase (An_{45-53} core) with rounded cores showing undulose or very patchy extinction and serrate rims more calcic than the cores, anhedral olivines with deformation lamellae, and abundant irregular or oblong, rounded opaques with serrate rims. Turbid green spinel grains were found in some sections and opaque aggregates occasionally enclose prisms of spotty grey apatite. Similar large apatites, sometimes with pink tinted rims, are sparsely scattered through the basalt. These mineral grains and aggregates are interpreted as xenocrysts derived from gabbroic rocks of deep-seated origin and are similar to constituents of xenoliths from other basic rocks of New South Wales (see Wilshire and Binns, 1961) and from the Kerguelen Archipelago.

DOLERITE

Dolerites consist of normally zoned olivine (average core composition about Fe_{70-75}) either in equidimensional, subhedral grains or in markedly elongate prisms, titanite, plagioclase (An_{58-60}), magnetite and ilmenite, and analcite. Pyroxene generally subophitically encloses plagioclase and sometimes encloses anhedral olivine grains. In severely altered rocks, plagioclase is extensively altered to alkali feldspar, interstitial analcite and anisotropic zeolites are abundant, and alteration of magnetite to leucosene reveals octahedral exsolution lamellae. The fabric and quantity of olivine vary considerably laterally in the large

dolerite flow (Fig. 2), but vertical sections in specific localities did not show conspicuous variation.

TRACHYTE

The dominant acid rock type, both as intrusions and flows, is trachyte, which consists largely of sanidine phenocrysts and olivine microphenocrysts set in a trachytic groundmass of sanidine laths, clusters of small aegirine or aegirine-augite and magnetite granules, analcite, anisotropic zeolites, and apatite. Badly altered plagioclase phenocrysts are present in some, and sanidine phenocrysts are frequently composite grains. Most trachytes contain elongate aggregates of aegirine and magnetite which probably pseudomorph amphibole phenocrysts though no relict amphibole was found. Large spotty grey apatite prisms are locally abundant, and aggregates of apatite prisms and anhedral opaques are rare; these are at least superficially the same as xenocrysts in the Twin Peaks type basalts. In two trachytes, aegirine prisms are elongate at a high angle to flow lines in sanidine laths, but nevertheless subophitically enclose the feldspar microlites which suggests crystallization of the aegirine after cessation of movement of the magma.

PHONOLITE

Three of the dome intrusions, the most prominent of which is Mt. Bulga, are nepheline phonolites. Mt. Bulga rock is crudely banded with layers rich in flow banded sanidine microlites alternating with those rich in euhedral nepheline microlites. Sanidine phenocrysts are sporadically present, but no olivine was found in any of the phonolites. Groundmass aegirine and magnetite occur in all, and elongate aegirine aggregates after amphibole are present in two of the phonolites. It is noteworthy that tuffaceous rocks extruded from the vent now occupied by Mt. Bulga phonolite are trachytes.

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The Palaeomagnetism of Peat's Ridge Dolerite and Mt. Tomah Basalt

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ABSTRACT—The palaeomagnetism of basic igneous rocks at Peat's Ridge and Mount Tomah, N.S.W., have recently been reported by Manwaring (1963); after partial demagnetization in alternating magnetic fields the directions of magnetization of the specimens from Peat's Ridge were consistent but those from Mt. Tomah remained scattered. The author has studied specimens from the same occurrences using partial *thermal* demagnetization techniques and has obtained results closely comparable with those of Manwaring. The unsuitability of the Mount Tomah basalt for palaeomagnetic purposes is discussed briefly.

The palaeomagnetism of certain igneous rocks of the Sydney Basin was discussed by Manwaring (1963) and in particular reference was made to the fine grained olivine dolerite intrusion at Peat's Ridge (near Gosford, N.S.W.) and the basalt flows capping Mt. Tomah (in the Blue Mountains of N.S.W.). Manwaring calculated a palaeomagnetic pole position for the specimens obtained from Peat's Ridge and from this was able to make an estimate of the geological age of the intrusion. He was also able to show that the specimens so far collected from Mt. Tomah are unsuitable for palaeomagnetic purposes. Even after partial demagnetization in fairly high alternating magnetic fields there was very little reduction in the scatter of the magnetic vectors of these specimens.

The author has been engaged in a study of thermal demagnetization of material and in the course of this study laboratory-induced magnetic moments of igneous rock and "thermal washing" or partial thermal demagnetization experiments were carried out on a number of specimens from Peat's Ridge and Mt. Tomah. The purpose of this note is to compare the results of these experiments with those of Manwaring.

Methods Employed

In these experiments the specimens were progressively demagnetized by heating them in a non-inductive electric furnace, through which a supply of nitrogen was maintained, and then cooling them in magnetic field free space. The earth's magnetic field was cancelled by passing currents through a system of large Helmholtz-type coils. The maximum magnetic field that may be left uncompensated by the coils, without resulting in a thermo-remanent moment, is readily calculated by extrapolating

the TRM data of Dickson (1962) to very low fields. For specimen T5C a value of 5×10^3 oersteds is indicated, which is substantially larger than the uncertainty in cancellation of the earth's field with the Helmholtz coils. However, as an additional precaution against the influence of stray laboratory fields, the specimens were rotated continuously about a vertical axis as they cooled; it was thus impossible for a stray horizontal field to have any effect unless it fluctuated coherently with the rotation of the specimens. The magnitude and direction of magnetization of each specimen was measured before and after each individual heating with an astatic magnetometer described by S. A. A. Kazmi (unpublished M.Sc. Thesis, University of Sydney, 1960). It was thus possible to remove the unstable magnetization and leave only the original thermo-remanent magnetization of the rocks.

Peat's Ridge

The NRM of a total of 20 specimens from five oriented samples collected by Manwaring was measured and then thermally washed in late 1961; all specimens were found to be reversely magnetized. The relative change in the intensity of magnetization, M_T/M_0 , with rise in temperature is shown in Fig. 1 for a typical specimen from all but one sample; the curves obtained from the specimens of the remaining sample are very similar to those of Fig. 1 and only tend to confuse the diagram. Curve 3 is of particular interest as the initial rise in M_T/M_0 is due to the removal of a relatively unstable component of magnetization. The directions of magnetization were statistically analysed using Fisher's treatment of dispersion on a sphere (Fisher, 1953) and k is an estimate of Fisher's precision parameter.



FIG. 1

The relative change in the intensity of magnetization with increase in temperature for the Peat's Ridge specimens. M_0 is the value of the NRM and M_T is the value of the intensity of magnetization at temperature T

TABLE I

Average direction of magnetization and comparison between unwashed and thermally washed specimens from Peat's Ridge

S =number of samples; N =number of specimens; D =declination of average direction; I =inclination of the average direction; R_s =vector resultant of sample means; R_N =vector resultant of specimens; k_w =within-sample precision; k_b =between-sample precision; k_o =over-all precision; a =half-angle of cone at 95% confidence ($P=0.05$) calculated from k_o

	<i>S</i>	<i>N</i>	<i>D</i>	<i>I</i>	<i>R_s</i>	<i>R_N</i>	<i>k_w</i>	<i>k_b</i>	<i>k_o</i>	<i>a</i>
NRM	5	20	176	+72	4.07	14.96	4	4	16	35°
Demag. 150°.. .	5	20	193	+71	4.98	19.86	136	161	620	5.6°

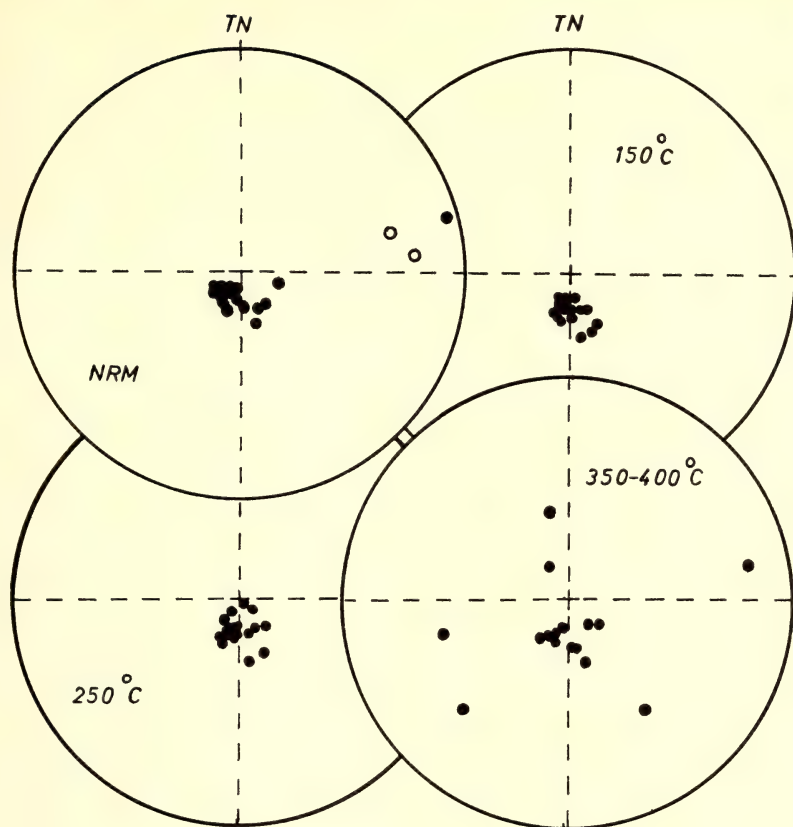


FIG. 2

Change in the direction of magnetization of the Peat's Ridge specimens with thermal washing

There is a considerable scatter in the NRM of the individual specimens; so much so that even the within-sample precision is very low ($k_w=4$), Table 1. A calculation based on the data given for the NRM in Table 1 indicates that the half-angle of the cone of confidence at the 95% level is 35° . This is larger than that reported by Manwaring and is probably due to the fact that the specimens may have been exposed to stray laboratory fields during the early stages of the investigations. However, after washing the specimens at progressively higher temperatures the scatter of the magnetization vectors was reduced. The change in the direction of magnetization with rise in temperature is displayed in Fig. 2 and the best agreement was observed to occur at 150°C .

The results of the investigations made on Peat's Ridge have been presented in Table 1 in exactly the same form as that used by Manwaring to allow an easy comparison of the data to be made. However, if the procedure of

taking only the sample mean directions is used, a slightly larger value (6°) is obtained for the half-angle at the cone of 95% confidence. This is due to the fact that there is a large difference in the number of specimens used within each sample; this would also explain the fact that the within-sample precision is a little less than the between-sample precision after washing.

After thermal washing to 150°C the palaeomagnetic pole position calculated was 66°S , 134°E ; this compares very favourably with 70°S , 134°E , calculated by Manwaring. It is of further interest to note that the close agreement of results has been obtained by using entirely different methods of treatment; alternating magnetic field "washing" on one hand and thermal "washing" on the other.

Mt. Tomah

In the middle of 1961 the effect of thermal demagnetization was observed on the NRM of 16 specimens taken from Mt. Tomah and it was

noted that "washing" did not reduce the scatter of the directions of magnetization, even at fairly high temperatures.

At the end of 1961 a fresh set of specimens, a total of 33 from three different sites, was collected from a new quarry face at Mt. Tomah. It was realized from previous experience that samples taken from the top of Mt. Tomah would be unsuitable and it was thought that these later samples would be satisfactory, palaeomagnetically.

All 33 specimens were gradually demagnetized in the same way as before. The precision of specimens (two from each sample) chosen to represent their sampler, was initially very low, 2.3, and at no stage during demagnetization did this situation improve; even at 175°C the precision was only 2.5. On applying the randomness test given by Watson (1956) it is seen that the distribution of directions was random (at the 5% level of significance) both initially and at 175°C.

It is not understood why there should be such a scatter in the direction of magnetization; however it was noticed that one sample taken from a road cutting at the top of Mt. Tomah was very strongly magnetized, the average intensity of magnetization being 78.5×10^{-3} emu/cm³, whereas the average for other samples taken from the same area was only 13.5×10^{-3} emu/cm³. Experiments similar to those described by Dickson (1962) showed that the TRM produced by cooling the specimens, with the high value of NRM, in 1.0 oe. was much smaller than their NRM; and assuming that the earth's field was 0.6 oe. at the time when the original magnetization was induced, the present

NRM is approximately five times the expected value. It seems likely, therefore, that the relatively high intensity of magnetization of this sample is due to lightning strike or possibly to some large man-made disturbances. The magnetization of the specimens from Mt. Tomah is held by a mineral phase with a fairly low Curie temperature (150°–200°C) and this has made it difficult to remove spurious effects without destroying the original magnetization. Also, as Manwaring suggested, the scatter in the direction of magnetization is probably due to the original thermo-remanent magnetization decaying with time leaving only randomly directed magnetizations.

Therefore it must be concluded, from the existing evidence, that the Mt. Tomah basalt is unsuitable for palaeomagnetic purposes.

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Seismic Investigations on the Foundation Conditions at the Royal Mint Site, Canberra

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ABSTRACT—An example of the application of the seismic refraction method to the investigation of foundation conditions on a limited building site is presented together with a discussion on the basis of detailed analytical methods of interpretation and the evaluation of measured seismic velocities in terms of rock strength.

Introduction

It is proposed to publish a number of examples of seismic surveys for the investigation of foundation conditions at proposed engineering or construction sites. The first of these examples is of the Royal Mint building site on the north-eastern corner of Commonwealth Avenue and King Edward Terrace, Canberra. The seismic survey was conducted during July, 1956, for the Department of Works, Canberra, by a geophysical party of the Bureau of Mineral Resources under the leadership of the author. The survey illustrates the application of conventional twelve channel equipment (Century Geophysical Corp.) to investigations of small sites in busy areas. Explosive charges, placed in auger holes at depths of about five feet in sandy alluvium, were used as the source of seismic energy. Shot nets were not necessary as the depth of the buried charges reduced the noise and likelihood of damage. An unpublished record of the survey exists in the Bureau of Mineral Resources (Hawkins and Stocklin, 1957).

Method

A number of variations of the seismic refraction method may be used in the investigation of the shallow subsurface conditions which are important in foundation considerations. All methods are based on the recording of the first arrival travel times of elastic waves and there is a close similarity between the detailed methods which yield an analysis of the depth of and velocity in the buried refracting layers. The recorded travel time data may be interpreted graphically by the construction of wavefront diagrams (Thornburgh, 1930 ; Hagedoorn, 1959) or more simply and rapidly by analytical methods. The analytical methods are based on the isolation of time-terms at individual shotpoint and recording stations. They involve

some approximations not required in the graphical methods but which are acceptable under most survey conditions.

For a brief explanation of the detailed analytical methods, consider the two-layer case shown in Fig. 1 in which a surface layer of seismic velocity V_0 overlies a bedrock layer of higher velocity V_1 . A shotpoint S acts as a source of seismic compressional waves which spread directly through the surface layer at the velocity V_0 , and are critically refracted through the top of the bedrock layer at the velocity V_1 . The critically refracted waves travelling along the interface produce wavefronts which are returned to the surface at the critical angle i_{01} . The wavefronts and raypaths of the waves arriving first at any point are shown in Fig. 1, together with a time-distance graph of the recorded travel times of the waves arriving first at the geophone stations placed on the surface. The slope of the segment of the time distance curve for the direct ray through the surface layer is $1/V_0$ and for the critically refracted ray is $1/V_1$ where V_1' is the apparent velocity of the refracting layer. The true velocity V_1 may be calculated from the apparent velocities recorded from opposite directions.

The critically refracted rays arrive first at geophone stations beyond the critical distance Δ . These rays have accepted a time delay in travelling down to the refractor beneath the shotpoint and a further time delay in travelling from the refractor to the surface at the geophone stations. The time lost has been recovered in travelling through the higher velocity (V_1) refracting layer. Each time delay is equal to the travel time for the segment of the raypath between the refractor and surface less the time saved by the lessened travel path in the refractor which results from the raypath to the surface being inclined at the critical angle i_{01} . The

time-terms used in the analytical methods are of two similar types, either equal to or closely related to this time delay.

The first is the *time-depth* which was introduced by Edge and Laby (1931) and defined by Hawkins (1961) and is equal to the time delay. In Fig. 2, the time-depth to the refractor at point G , t_G , may be written

$$t_G = (GX/V_0 - PX/V_1) \quad (1)$$

from which the expression for the depth to the refractor along the normal to the refractor, Z_G , may be readily obtained.

$$Z_G = t_G V_0 / \cos i_{01} \quad (2)$$

It is apparent from Fig. 2 that for the time-depth the refractor is assumed to be plane in the limited region below the geophone station G , between the points X and Y from which the

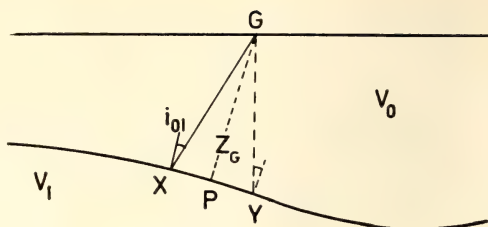


FIG. 2

Ray paths in definition of time-depth

recorded rays leave the refractor. This approximation is not as great as for the classical time-term, the *intercept-time* T_i in Fig. 1, for which the refractor is assumed to be plane over the entire length of shotpoint and geophone spread.

The second time-term commonly used in the detailed analytical methods is the *delay-time*

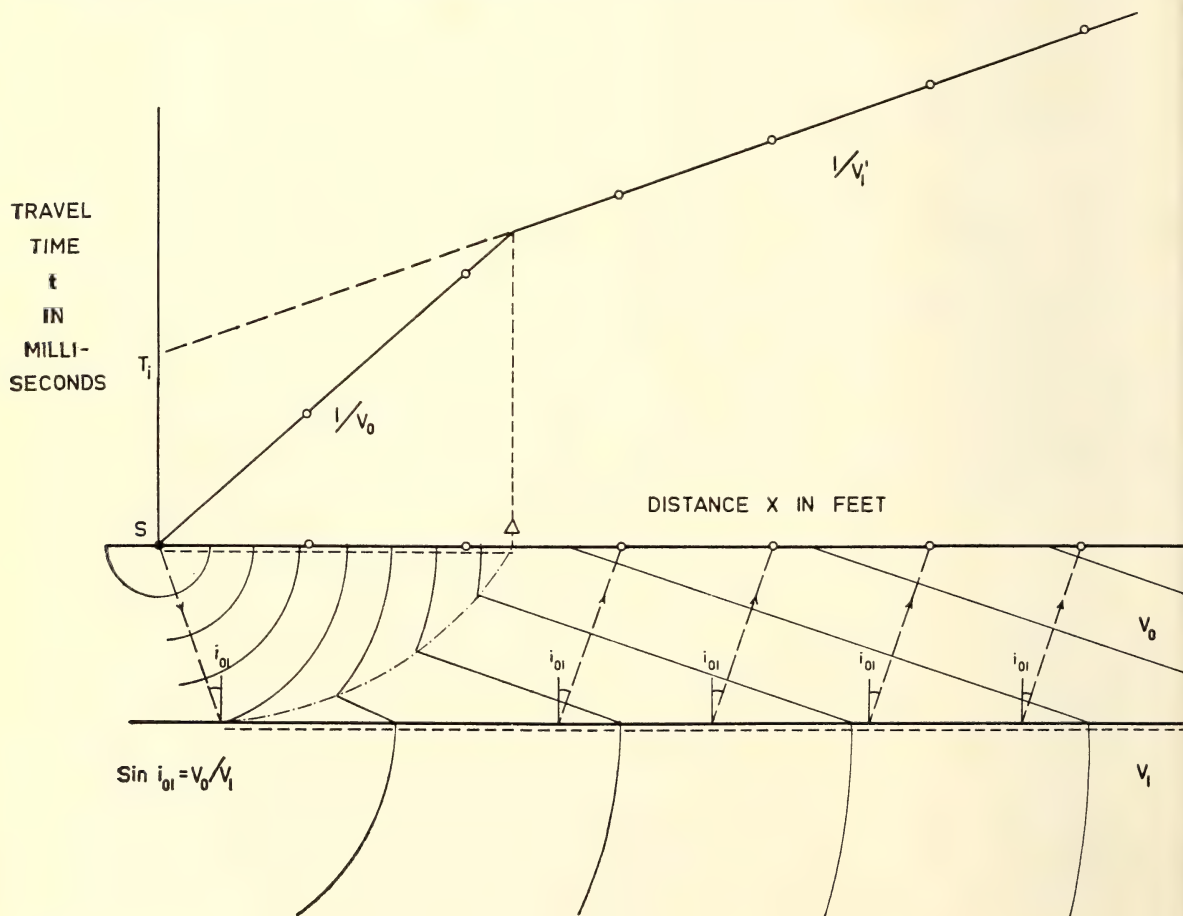


FIG. 1

The two-layer case of a surface layer of velocity V_0 with an underlying refracting layer of higher velocity V_1 . The wavefronts and ray paths of the direct or critically refracted rays arriving first at any point are shown together with the time-distance graph of travel times of the first arrival waves at the surface

which was introduced by Gardner (1939) and defined by Nettleton (1940). The delay-time differs in the nature of the approximation made by the assumption that the refractor is horizontal at the points from which the recorded rays leave the refractor. The effect of dip is neglected.

The Reciprocal Method which was used in the survey of the Royal Mint site is based on the use of the time-depth and has been fully

described by Hawkins (1961). The method of isolating the time-depth and the treatment of refractors with multilayered overburdens will not be discussed here. However, the nomogram for obtaining the velocity term $V_0/\cos i_{01}$ in equation 2 is reproduced in Fig. 3. This is presented in the general form for a refractor of velocity V_n with an overlying layer of velocity V_m . The nomogram also has application to

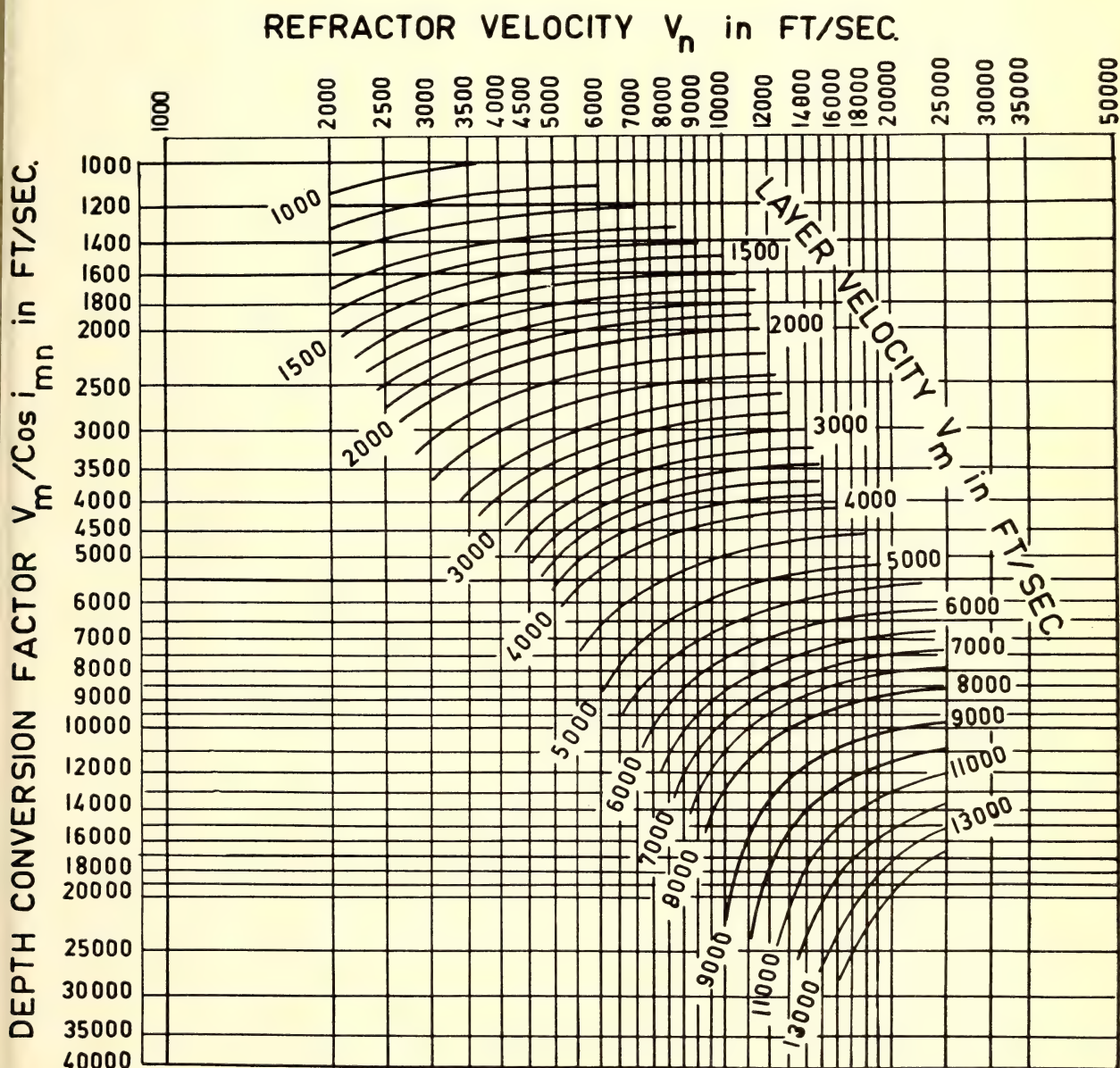
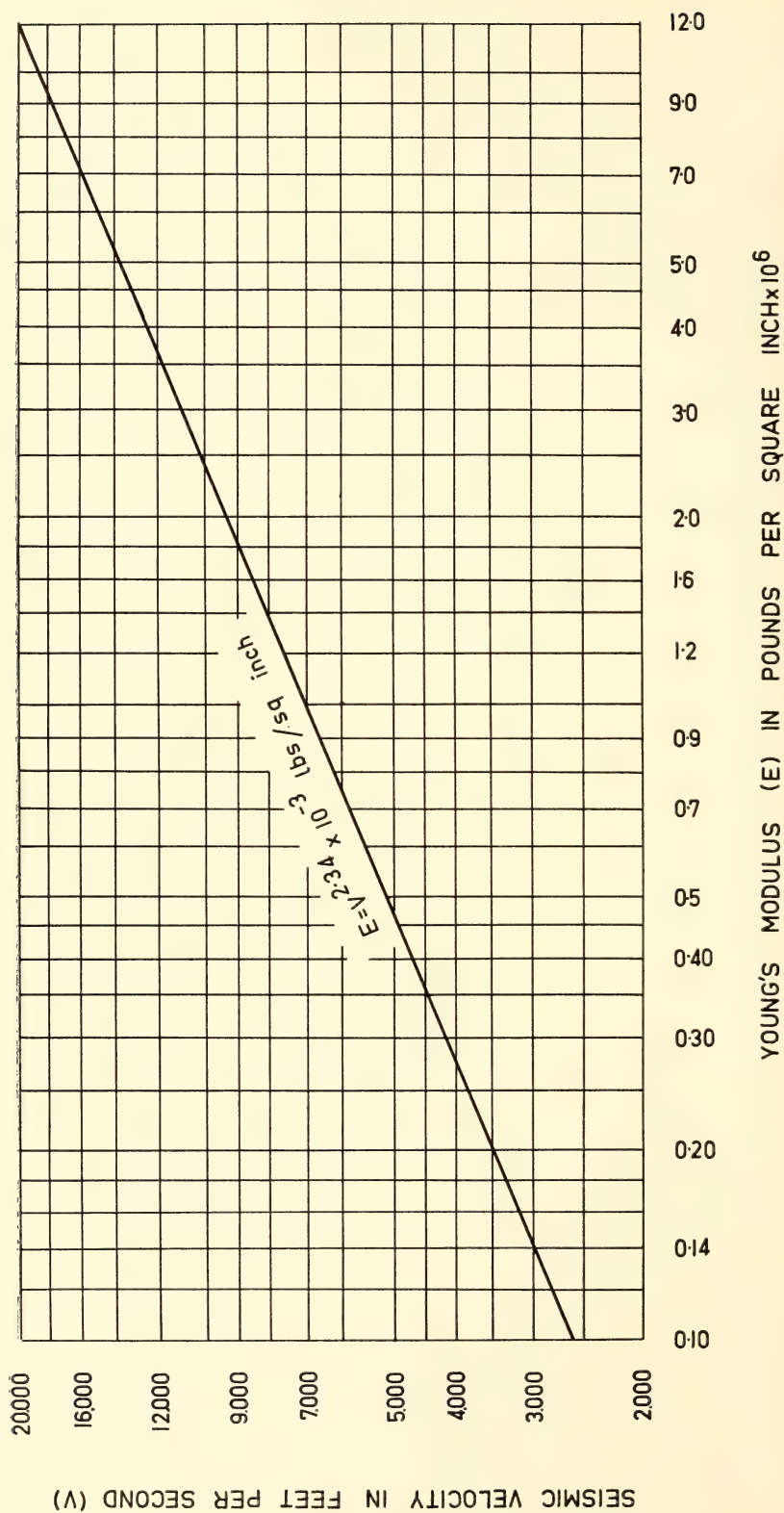


FIG. 3

Nomogram of "depth conversion factor" $V_m/\cos i_{mn}$ for a layer of velocity V_m and underlying refractor of velocity V_n



To convert millions of pounds/sq inch to dynes/sq cm multiply by 6.89×10^{10}

FIG. 4

Approximate empirical relation between the Young's Modulus and the compressional wave velocity in consolidated rocks

cases with multilayered overburdens (Hawkins, 1961, pp. 808-809).

For surveys under "normal" conditions and without drilling control, the errors in depth determinations usually expected may reasonably be stated as having an equivalent random error within ± 10 to 15 per cent with a possible bias within about 10 per cent of the calculated depths.

The analysis of the velocities in the refractor in the Reciprocal Method is carried out by the subtraction of the time-depths from the recorded travel times at geophone stations beyond the critical distance. This removes the effect of dip and of variations in depth and/or overburden velocity. The refractor velocities may be determined directly from the slope of the corrected time-distance curves. These velocities refer to waves travelling in the plane of the refractor and in the direction of the traverse and can vary for anisotropic rocks.

Velocity as a Guide to Rock Strength

The accurate determination of seismic velocities is important in engineering considerations since the velocity is controlled by the fundamental parameters of elastic strength and density. If both shear and compressional waves velocities and the density are known, the dynamic elastic constants may be calculated directly from a number of well known equations (Swain, 1962). The dynamic moduli correspond to the initial tangent moduli of the stress-strain curves for an instantaneously applied load and are usually higher than those obtained in static tests.

However, in the normal seismic method only the compressional wave velocities are determined. The measured velocities may be evaluated qualitatively in terms of the degree of weathering and fracturing of a known rock type, or an approximate empirical relation with rock strength may be sought. Such a relation between the compressional wave velocity (V) and the Young's Modulus (E) is shown in Fig. 4. This was presented as a graphical relation by Brown and Robertshaw (1953) from some early and sometimes questionable results of Reich (1930). The relation has been replotted on logarithmic scales and the derived formula is

$$E = V^{2.34} \times 10^{-3} \text{ lb/sq. inch.}$$

The data used to derive this relation is not comprehensive and the application in the range of low velocity unconsolidated rocks is doubtful.

It has been included only as a general guide to evaluating the measured velocities in consolidated rocks.

Geology

The Royal Mint site is located on the Riverside Formation which consists of calcareous shales and mudstones, fine-grained sandstones, prominent limestone lenses, tuffaceous sediments, tuffs and rhyolites (Opik, 1955). This formation is part of the Canberra Group and is of Lower Silurian age.

Results

The locality and traverse plans of this survey are shown in Fig. 5 and the results of the seismic survey showing the calculated profiles of the weathered and unweathered bedrock are shown in Fig. 6.

The seismic results show the presence of a surface layer with average seismic velocities ranging from 2,400 to 2,800 ft/sec and a thickness of 26 to 38 feet. The low velocities indicate unconsolidated material. Below the surface layer, an intermediate layer with seismic velocities of 6,000 and 8,000 ft/sec was indicated which extended to depths between 69 and 118 feet. Velocities in this range indicate weathered and/or broken rock (8,000 ft/sec) to decomposed rock (6,000 ft/sec), and this layer is interpreted as a weathered layer. A detailed depth profile of the top of this weathered layer was not requested and the depths were not determined at all stations.

The layer underlying the intermediate weathered layer shows distinct areas with two velocity ranges: 8,000 to 11,500 ft/sec and 16,000 to 17,000 ft/sec. Since experience has shown that anomalous low velocity zones within the bedrock correspond with zones of shear or fracture, the lower velocity range is interpreted as weathered to partly weathered rock occurring within a zone of shear or fracture. The thickening of the weathered layer and the occurrence of the lower velocities within the weathered layer (6,000 ft/sec) over this zone support this interpretation. The postulated shear zone is indicated as low velocity bedrock in Fig. 5 with close hatching. The areas of high velocity (16,000 to 17,000 ft/sec) are interpreted as unweathered rock outside the zone of shear. The high velocities probably represent unweathered limestone lenses, but it is reasonable to assume that underlying interbedded sediments would also be unweathered. In Fig. 6 the intermediate weathered layer is

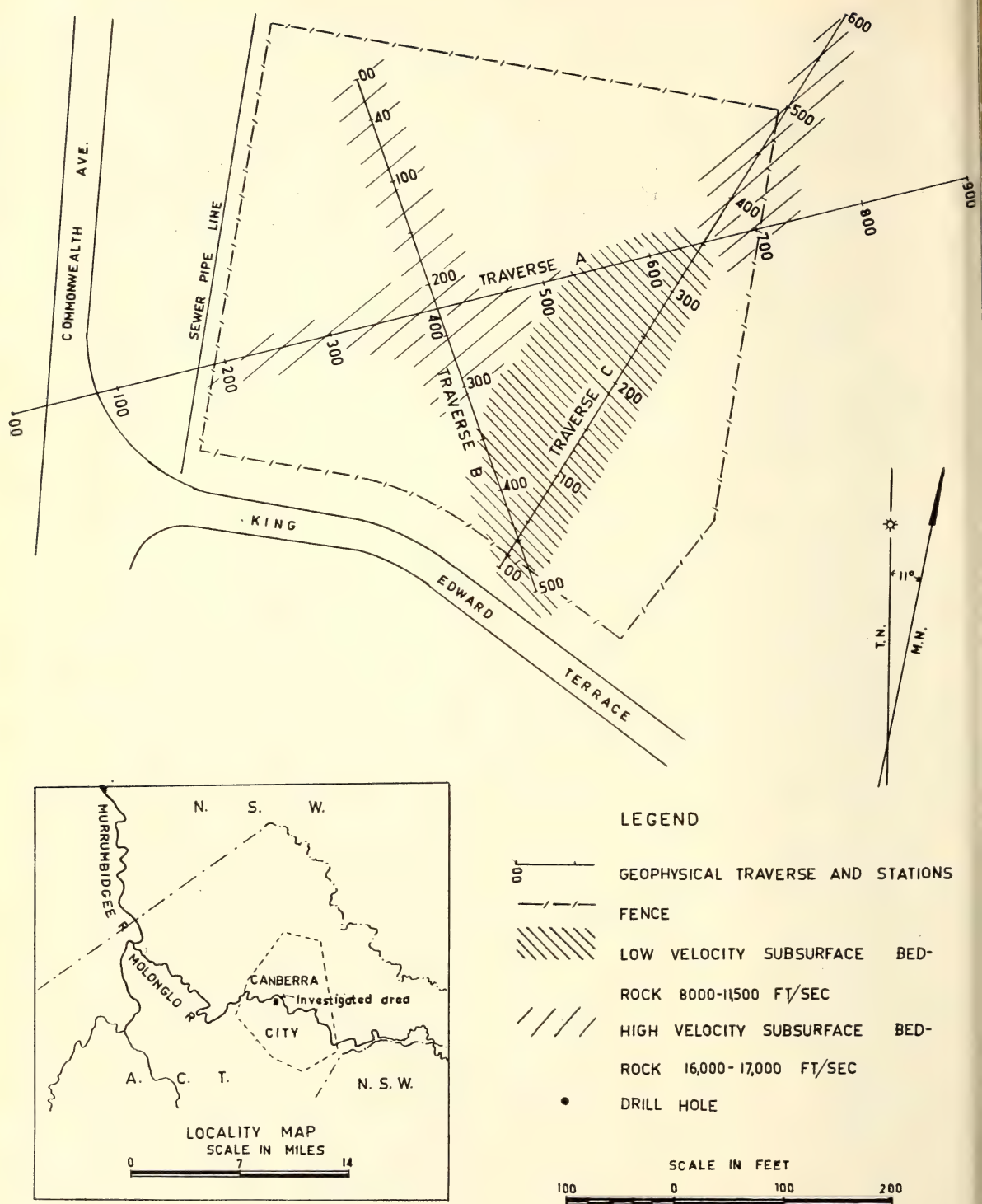
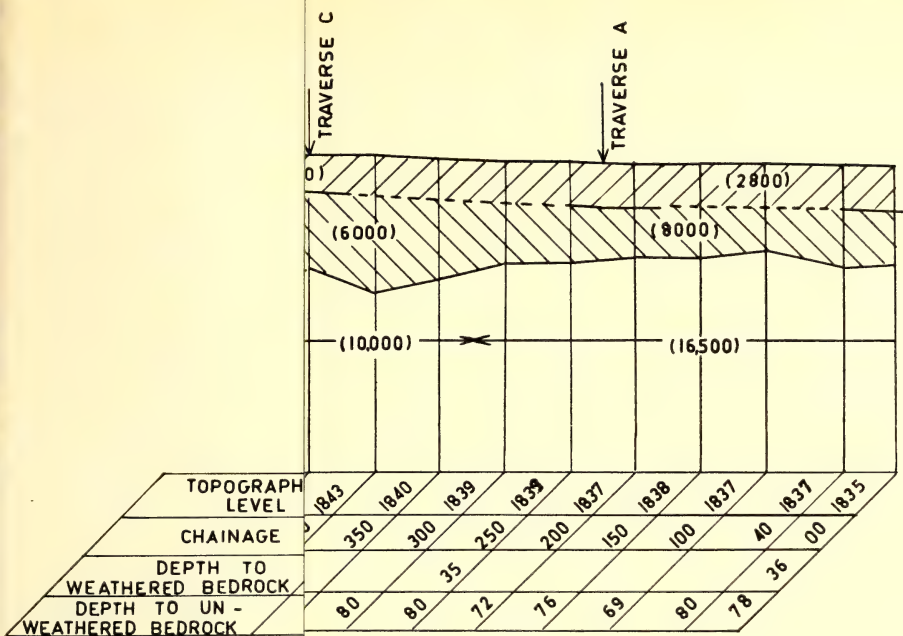


FIG. 5

Locality and traverse plan for the survey of the Royal Mint site, Canberra

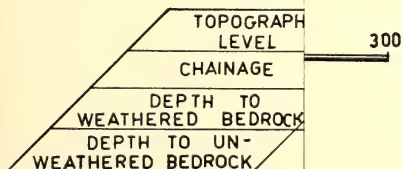


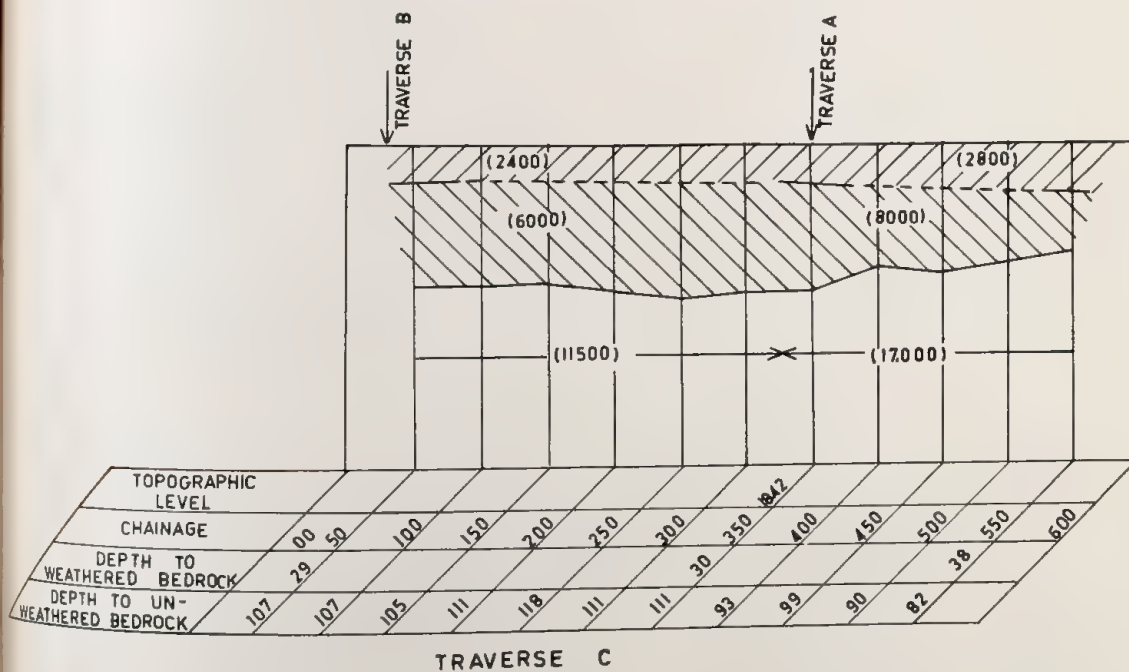
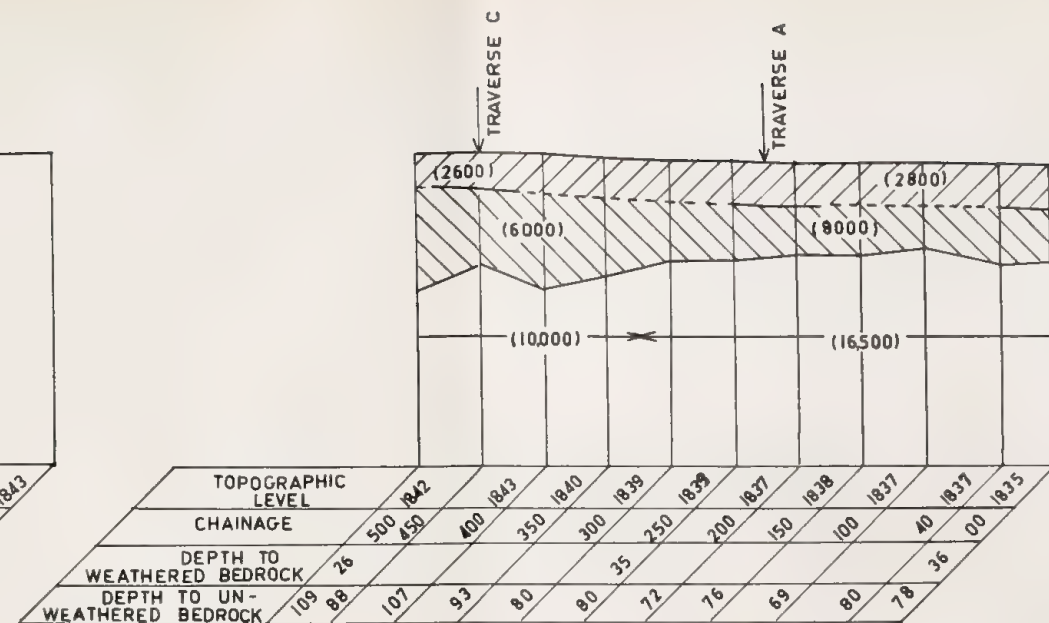
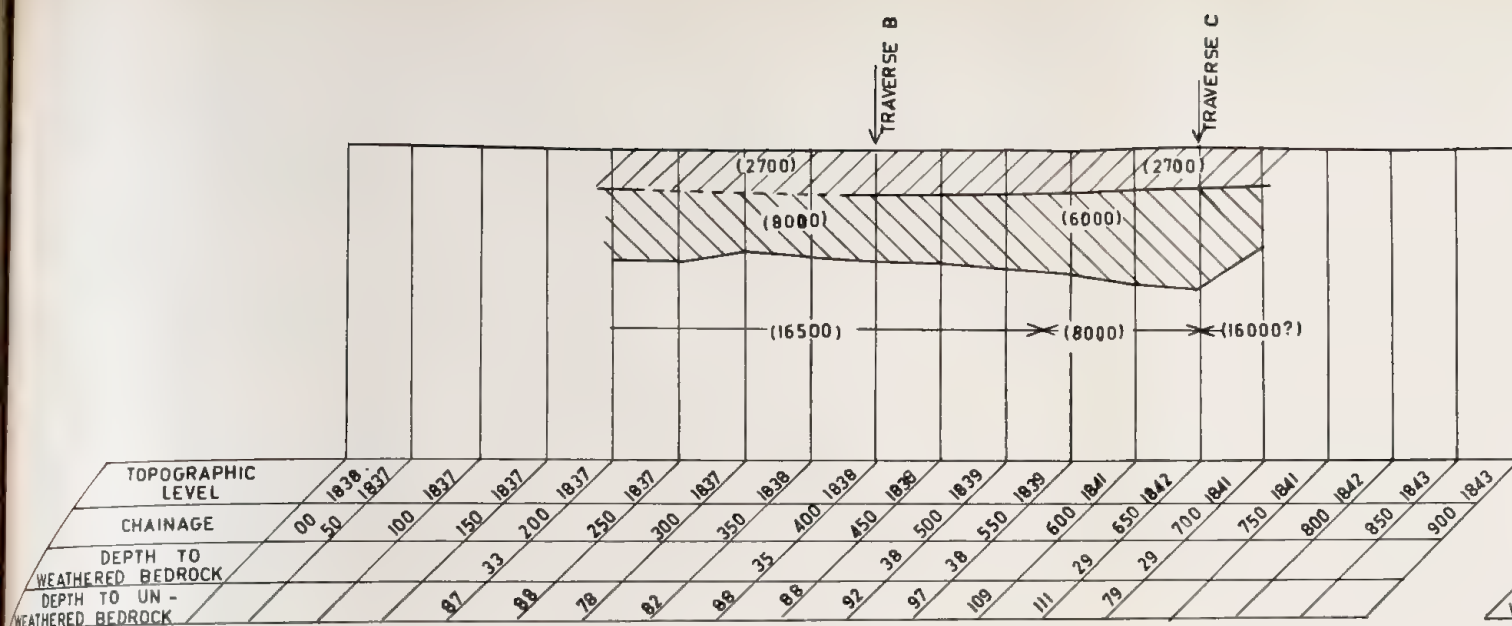
TRAVERSE B

a layer (Completely weathered consolidated rock).

red bedrock.

hered or slightly weathered
neared bedrock.





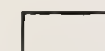
LEGEND



Surface layer (Completely weathered or unconsolidated rock).



Weathered bedrock.



Unweathered or slightly weathered and sheared bedrock.

SCALE IN FEET

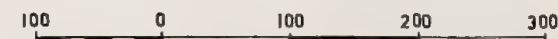


FIG. 6

Results of seismic survey showing calculated depths to weathered and "unweathered" bedrock

referred to in general terms as weathered bedrock and the underlying layer of increased velocity as "unweathered" bedrock.

Conclusions

The seismic investigations disclose the presence of a surface layer of unconsolidated material and a thick weathered layer overlying "unweathered" bedrock. The distribution of low seismic velocities in both the weathered and "unweathered" bedrock layers indicates the presence of a zone of shear or fracture on the western part of the proposed site.

The alternative to very deep foundations on unweathered bedrock (at depths exceeding 69 feet) is the use of the weathered bedrock layer which is indicated at depths of the order of 26 to 38 feet. The measured seismic velocity in this layer outside the zone of shearing (8,000 ft/sec) indicates weathered rock, and within the zone of shearing (6,000 ft/sec) indicates very weathered to decomposed rock.

Subsequent Drilling

Some subsequent check drilling is available from a limited check drilling programme on the adjacent Acton Weir site, which was carried out in 1958 (Gardner, 1958). A single borehole (DDH3) was located on the proposed Royal Mint site to check the zone of shear or fracture. The approximate location is in the vicinity of stations A550 and A600. The borehole entered a zone of shearing and fracturing in which weathering of the bedrock could be expected to continue to considerable depths (Gardner, 1958, p. 6). The hole was terminated at a depth of 33 feet in soft, decomposed bedrock (siltstone) which was first encountered at a depth of 18 to 19 feet.

A second borehole (DDH4) was located just off the site to the west between the Acton and Royal Mint sites, on the southern extremity of

the centreline traverse of the Commonwealth Avenue bridge site. The Commonwealth Avenue traverse showed the unweathered bedrock refractor at a depth of approximately 35 feet with a measured velocity of 16,000 ft/sec. This shows close agreement with the drilling which encountered hard impure limestone at a depth of 36 feet.

Acknowledgements

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The Palaeomagnetism of Some Igneous Rocks of the Sydney Basin, N.S.W.

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Introduction

In the area of the Sydney Basin there are a large number of basic igneous rock bodies whose ages are defined only within wide limits. They are intruded into or extruded upon the Triassic Hawkesbury and Wianamatta Groups. These rocks are thus either Upper- or post-Triassic in age, and have generally been considered as Tertiary (David, 1950). A palaeomagnetic study was made of three of these rock bodies (Fig. 1) with a view to obtaining a more precise estimate of their age.

(1) A dyke of porphyritic olivine dolerite at Luddenham, N.S.W. ($33^{\circ} 53' S$, $150^{\circ} 40' E$; map ref.: 703120, Liverpool 1-mile Military, No. 422, Zone 8).

(2) An intrusive (? laccolith) of fine grained olivine dolerite at Peat's Ridge, N.S.W. ($33^{\circ} 19' S$, $151^{\circ} 12' E$; map ref.: 217805, Gosford & Norahville 1-mile Military, Nos. 410 & 411, Zone 8).

(3) The basalt flow or flows capping Mt. Tomah in the Blue Mountains of N.S.W. ($33^{\circ} 32' S$, $150^{\circ} 26' E$; map ref.: 415550, Katoomba 1-mile Military, No. 415, Zone 8).

This study was begun as part of an Honours thesis in the Department of Geology and Geophysics at the University of Sydney, and completed in the Department of Geophysics, Australian National University, Canberra. I wish to thank Dr. A. A. Day at Sydney, and Mr. E. Irving at Canberra, for much help and advice on this work.

Methods Employed

In each case, samples were distributed as evenly as possible over the total exposures of rock available. At Luddenham, exposure is restricted to three small excavations made some years ago when the rock was quarried as road

metal for a short time. Seven oriented samples were taken along about 50 yards of the dyke. At Peat's Ridge, five oriented samples were taken from different places on the working face of the road metal quarry in operation there. On Mt. Tomah, six oriented samples were taken from cuttings on a road (Bell's Line of Road) which crosses the basalt outcrop. Between one and three cylindrical specimens ($1\frac{1}{4}$ inches in diameter; between $\frac{1}{2}$ and $1\frac{1}{4}$ inches in height) were cut from each oriented sample.

The intensities and directions of the natural remanent magnetization (N.R.M.) of the specimens were measured firstly on the astatic magnetometer in the Department of Geology and Geophysics, Sydney University, in 1960, and later on an astatic magnetometer in the Department of Geophysics, Australian National University, in 1961-62. The stability of the specimens was studied by demagnetization in alternating magnetic fields (Thellier and Rimbart, 1954 and 1955), using the apparatus and procedures described by Irving, Stott and

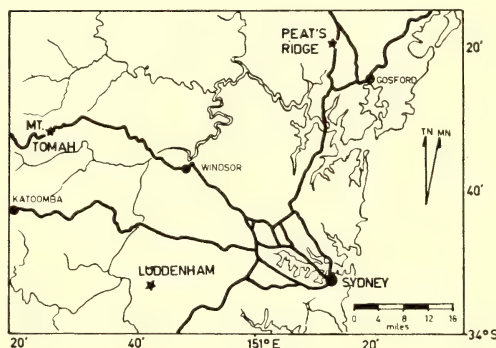


FIG. 1

Sketch map of Sydney area—sampling sites indicated by stars

TABLE 1

Average directions of magnetization and statistical data for Luddenham dolerite dyke and Peat's Ridge dolerite intrusion

S =number of samples; N =number of specimens; D =declination of average direction; I =inclination of average direction; R_s =vector resultant of sample means; R_N =vector resultant of specimen directions; k_w =within-sample precision; k_b =between-sample precision; k_o =over-all precision; a =half-angle of cone of 95% confidence ($P=0.05$)

	Luddenham			Peat's Ridge		
	NRM Sydney	NRM Canberra	Demag. 225 oe.	NRM Sydney	NRM Canberra	Demag. 225 oe.
S	7	7	7	5	5	5
N	15	15	15	10	10	10
D	117°	117°	314°	172°	175°	190°
I	-84°	-84°	-79°	+70°	+66°	+69°
R_s	5.70	5.86	6.72	4.97	4.95	4.96
R_N	12.33	12.19	14.06	9.93	9.86	9.92
k_w	294	25	27	1500	147	362
k_b	5	6	30	128	100	132
k_o	34	36	138	614	373	558
a	24°	24°	12°	6°	7°	6°

Ward (1961). The method adopted was to select a single specimen from each of a number of samples (from four to six) from each of the rock bodies; these sets of specimens are defined as the "pilot" specimens. These pilot specimens were then treated in progressively stronger alternating magnetic fields, their magnetizations being measured after each treatment. The alternating field strength ($H_p \sim$) quoted is always the peak value. For each set of pilot specimens the variation of the precision of the directions with treatment was studied.

The changes in the intensity of magnetization of the pilot specimens with progressive partial demagnetization are plotted as a graph of the ratio M/M_o against the alternating field ($H_p \sim$), where M_o is the initial (N.R.M.) intensity of the specimen, and M is the intensity remaining after treatment.

The directions were analysed statistically using Fisher's treatment of dispersion on a sphere (Fisher, 1953). The precision used is k , the estimate of Fisher's α . In order to study the precision of the directions within- and between-samples for the same rock unit, the two-tier statistical analysis given by Watson and Irving (1957) was used. The estimated precision of the specimen directions from samples

(within-samples precision) is denoted by k_w ; the between-sample precision by k_b ; and the over-all precision by k_o . The half-angle (a) of the cone of 95% confidence is calculated from k_o . This rather sophisticated analysis was carried out in order to make comparisons between the Sydney and Canberra measurements.

All directions of magnetization are plotted on polar stereographic projections (Wulff net). Negative inclinations (N pole up) are plotted as circles on the upper hemisphere of the projection; positive inclinations (N pole down) are plotted as dots on the lower hemisphere. Pole positions are plotted on a Lambert polar equal-area projection (Schmidt net) of the Earth's southern hemisphere.

Results from Luddenham Dyke

The directions of the N.R.M. of the Luddenham specimens as measured in (a) Sydney, and (b) Canberra are plotted in Fig. 2. A comparison shows that the two separate measurements for individual specimens do not, in most cases, agree. This is particularly evident in the directions in the SE quadrant.

A statistical comparison of the results from the two sets of readings is given in Table 1. The average direction for both sets is exactly

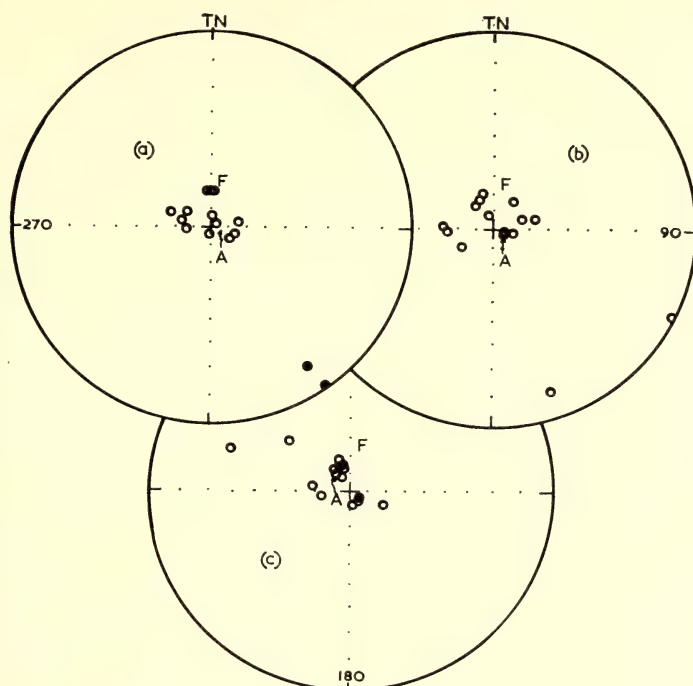


FIG. 2

Directions of magnetization of the specimens from Luddenham dyke

(a) N.R.M. directions as measured in Sydney in 1960

(b) N.R.M. directions as measured in Canberra in 1961-62

(c) Directions of magnetization after treatment in an alternating magnetic field of 225 oersteds (peak)

The average direction is indicated by "A" and the direction of the present Earth's field by "F"

the same, and the between-sample precision and over-all precision of each are very similar. Yet the within-sample precision is much less for the Canberra readings than for the Sydney ones. This could be due to the Canberra readings being of lower accuracy, but repeat measurements on specimens at *both* Sydney and Canberra give results whose standard deviation is approximately 2° , which is too small to explain the differences observed in Fig. 2. It would appear therefore that the scatter of the individual specimen directions has increased in the period of one year between measurements. This shows an instability of the magnetizations of the specimens which would be due to a randomly directed component of viscous magnetization imposed on them during this period (the specimens were stored in random positions in the earth's field).

In Fig. 3 are plotted the changes in the directions of magnetism of the six pilot specimens as the alternating field strength was increased. The variation of the precision between the

directions of these specimens is plotted in Fig. 4. It is apparent that the greatest precision is obtained after partial demagnetization in a field of 225 oersteds (peak). The other specimens from Luddenham were treated in this field, and their directions are plotted in Fig. 2 (c). The average direction and statistical data are given in Table 1. It can be seen that there is little increase in the within-sample precision, but that there is a large increase in the between-sample precision and in the over-all precision.

There are two methods by which the optimum partial demagnetization field may be chosen, and it is of interest to compare them. Firstly, there is the method used above. Secondly, there is the method used by As and Zijdeveld (1958), in which the changes in the directions of specimens are studied individually. These workers found that with progressive demagnetization the unstable component of magnetization diminishes and even vanishes without greatly affecting the direction of the original stable magnetization. If the unstable component

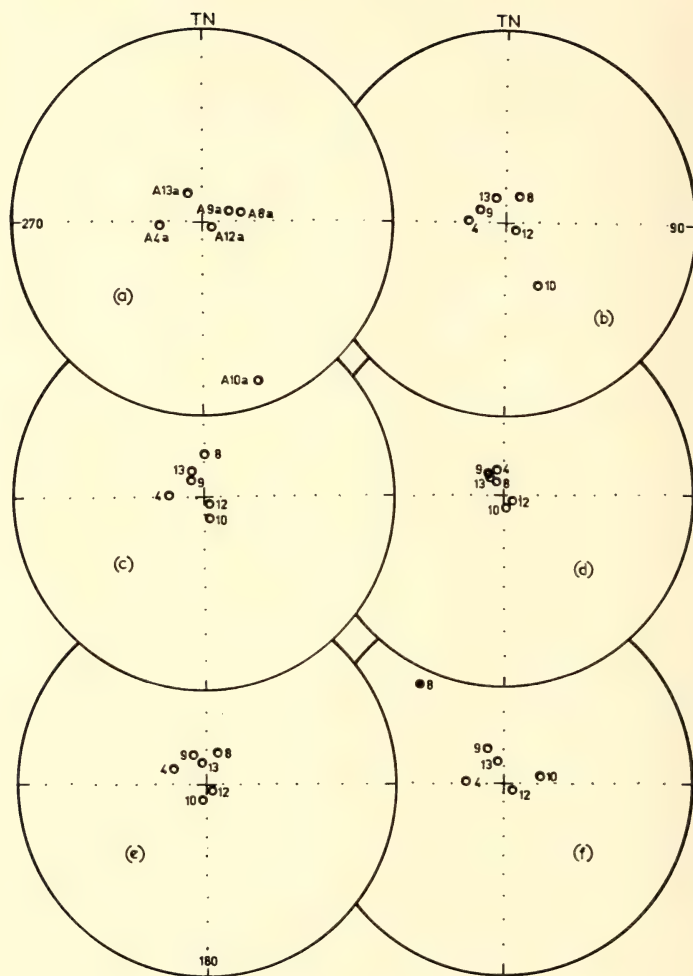


FIG. 3

The changes in the directions of magnetization of the Luddenham pilot specimens (A4a, A8a, A10a, A12a and A13a) with treatment in alternating fields

The directions plotted are :

- (a) N.R.M.'s
- (b) After treatment in 75 oersteds (peak)
- (c) After 150 oe.
- (d) After 225 oe.
- (e) After 300 oe.
- (f) After 375 oe.

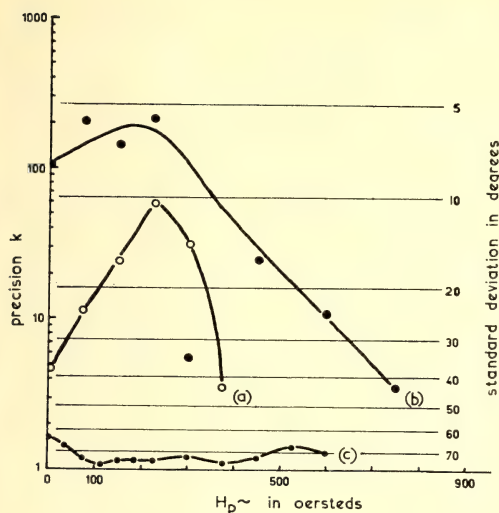


FIG. 4

The variation of the precision k (Fisher, 1953) of the directions of the pilot specimens from (a) Luddenham, (b) Peat's Ridge, and (c) Mt. Tomah, with treatment in alternating fields ($H_p \sim$). The precision k is plotted on a logarithmic scale.

Also shown are the values of k at which the standard (circular) deviation (Creer, Irving and Nairn, 1959) has values as indicated on the figure. Thus the variation of this circular standard deviation with $H_p \sim$ can also be seen

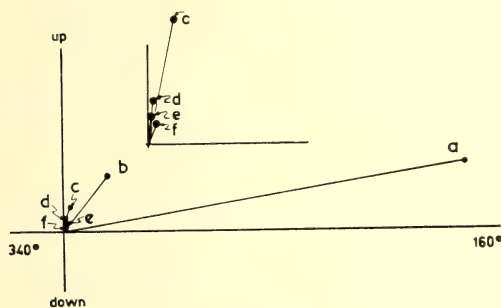


FIG. 5

Vector plot of the changes in the directions of specimen A10a with treatment in alternating fields. The vectors are plotted in the vertical plane which lies in the azimuth of 160° (true). The lengths of the vectors are proportional to the remaining intensity of magnetization after each treatment, and the angles of inclination are plotted in the vertical plane. The alternating field strengths and intensities of magnetization (M) are as follows: (a) N.R.M.; $M = 191 \times 10^{-4}$ emu/cc; (b) 75 oe; $M = 33 \times 10^{-4}$ emu/cc; (c) 150 oe; $M = 11.5 \times 10^{-4}$ emu/cc; (d) 225 oe; $M = 3.8 \times 10^{-4}$ emu/cc; (e) 300 oe; $M = 2.5 \times 10^{-4}$ emu/cc; (f) 375 oe; $M = 1.9 \times 10^{-4}$ emu/cc. Inset are shown the vectors c, d, e and f, to a larger scale

is at some angle to the direction of the stable one, the direction of the total magnetization rotates with demagnetization, until a stage is reached where the resulting magnetization remains constant in direction and decreases in magnitude. It is then assumed that the unstable component has been completely removed, and that the constant direction obtained is that of the original, stable magnetization of the rock. The final constant directions of all the specimens are then combined to give the average result.

This process of obtaining a final, relatively constant direction can be seen in Fig. 5, where the changes in direction and intensity of specimen A10a are plotted as vectors. (A10a is the only specimen which has a sufficiently large change in direction for such a figure to be drawn.) It can be seen from this figure that the field strength chosen for treating the remainder of the Luddenham specimens (225 oe.) gives a direction which lies within the range of this final, constant direction. Thus the two methods agree in this particular case.

The manner in which the intensities of magnetization (moments) of the pilot specimens change is shown in Fig. 6 by a plot of M/M_0 against $H_p \sim$: the values of M/M_0 at 225 oe. are compared with the total angular change in direction of magnetization for each specimen in Table 2. It is apparent that, in a general way, the smaller the ratio—i.e. the greater the relative decrease in moment—then the less the stability—i.e. the greater the change in direction. Thus, referring to Fig. 6, specimen A10a is the least stable and specimens A12a and A13a the most stable.

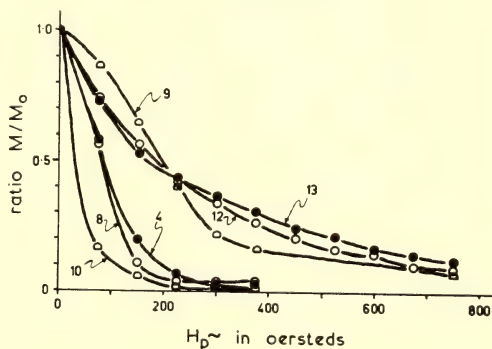


FIG. 6

The variation of the ratio M/M_0 with alternating field strength ($H_p \sim$) for the Luddenham pilot specimens. M_0 is the initial (N.R.M.) intensity of magnetization, and M the intensity after treatment

TABLE 2

Comparison of the total angular change in the directions of magnetization of the pilot specimens from Luddenham (after treatment at 225 oersteds) with the ratio of the intensity remaining (M) to the initial (N.R.M.) intensity (M_0)

Specimen	M/M_0 (225 oe.)	Angular Change
A10a	0.02	74°
A8a	0.04	28°
A4a	0.07	27°
A9a	0.41	25°
A12a	0.43	1°
A13a	0.43	8°

Results from the Peat's Ridge Dolerite

The magnetizations of the Peat's Ridge specimens differ from the Luddenham ones in that they are all reversely magnetized (inclinations positive), and that the precision of their N.R.M. directions is greater.

The N.R.M.'s were measured initially in Sydney, and then again in Canberra after a

lapse of almost two years. The two sets of directions obtained are plotted in Figs. 7 (a) and 7 (b). The precision of the Canberra measurements is less than that of the Sydney ones (see Table 1)—the within-sample precision shows a large decrease whereas the between-sample precision remains sensibly the same. For the same reasons given before, this increased scatter of individual specimen directions is considered to be due to instability caused by a random component of viscous magnetization.

Four pilot specimens were selected and treated in alternating magnetic fields. The changes in directions are shown in Fig. 8, and the variation of the precision among these specimens is shown in Fig. 4, together with the variation in circular standard deviation.

The greatest precision is obtained, once again, by treatment in a field of 225 oersteds. The directions of all the Peat's Ridge specimens after treatment are shown in Fig. 7 (c), and the average direction and statistical data are given in Table 1.

In this case, the within-sample precision is increased, but does not regain the value it had

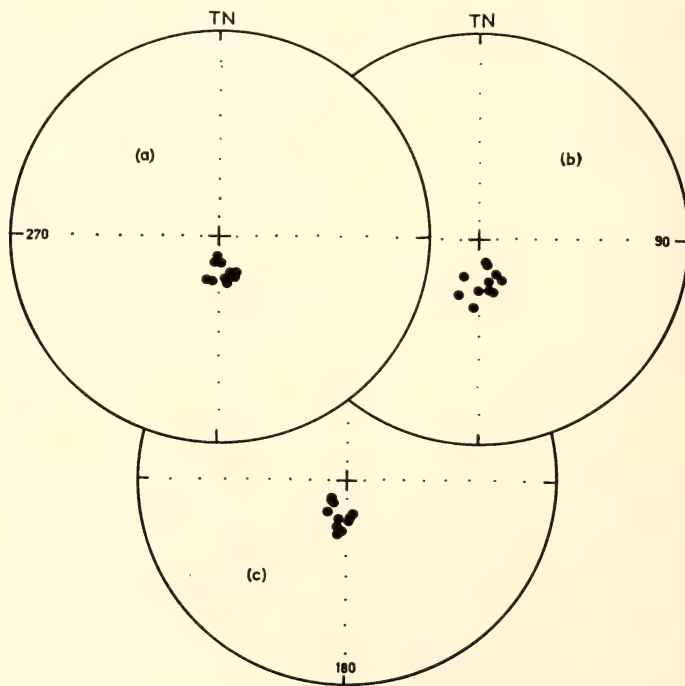


FIG. 7

Directions of magnetization of the specimens from the Peat's Ridge intrusion

- (a) N.R.M. directions measured in Sydney
- (b) N.R.M. directions measured in Canberra
- (c) Directions after treatment in an alternating field of 225 oersteds



FIG. 8

The changes in the directions of the Peat's Ridge pilot specimens (A20c, A22c, A23c and A26c) with treatment in alternating magnetic fields. The directions plotted are :

- (a) N.R.M.'s
- (b) After treatment in 150 oersteds (peak)
- (c) After 225 oe.
- (d) After 300 oe.
- (e) After 450 oe.
- (f) After 750 oe.

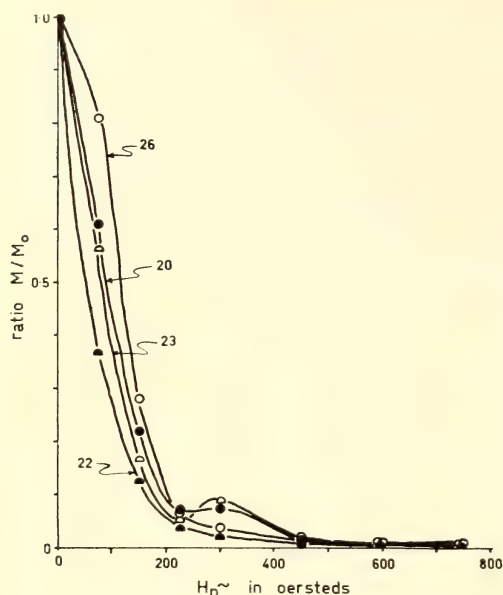


FIG. 9

The variation of the ratio M/M_0 with alternating field strength ($H_p\sim$) for the Peat's Ridge pilot specimens

when the N.R.M.'s were measured in Sydney. On the other hand, the between-sample precision increased to a value slightly greater than originally. And so the over-all precision is not appreciably less than that of the Sydney measurements. It would thus seem that the greater part of the random viscous magnetization imposed in the period between the N.R.M. measurements was removed by the treatment in alternating magnetic fields. Also, since the

average direction has changed, a common and more-or-less constant unstable component has been removed from all specimens.

The ratio M/M_0 is plotted against $H_p\sim$ in Fig. 9 for the pilot specimens.

Results from the Mt. Tomah Basalts

Both the Sydney and Canberra measurements of the N.R.M.'s of the Mt. Tomah specimens gave a very large scatter of directions. These directions are plotted in Figs. 10 (a) and 10 (b).

Six pilot specimens were selected and treated in alternating magnetic fields. The changes in their directions are shown in Fig. 11, and the variation of the precision of these directions is shown in Fig. 4. The precision remains very low at all stages of the treatment. There is no optimum treatment field indicated by the curve in Fig. 4, as was the case for both Luddenham and Peat's Ridge, and so the remainder of the specimens were not treated at all.

The variation of M/M_0 for Mt. Tomah is plotted in Fig. 12, and shows a very swift decrease in the intensities of the pilot specimens (compare with Figs. 6 and 9).

On applying the randomness test of Watson (1956) to the directions obtained from the pilot specimens during treatment, it was found that the distribution of directions was random (at the 5% level of significance) initially and at all stages of the treatment. The ratio k/k_{slg} (k_{slg} is the minimum value of k for the distribution of directions to be significant, as calculated from the tables of the significance points of R given by Watson) varied between 0.7 and 0.5. The cause of this wide scatter is not known,

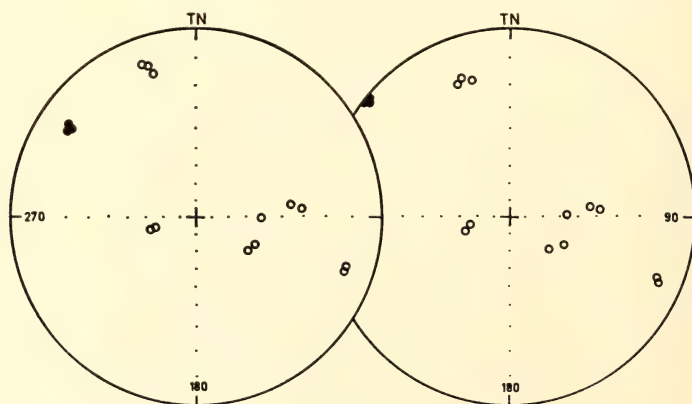


FIG. 10

Directions of magnetization of the specimens from the Mt. Tomah basalts

- (a) N.R.M. directions as measured in Sydney
- (b) N.R.M. directions as measured in Canberra

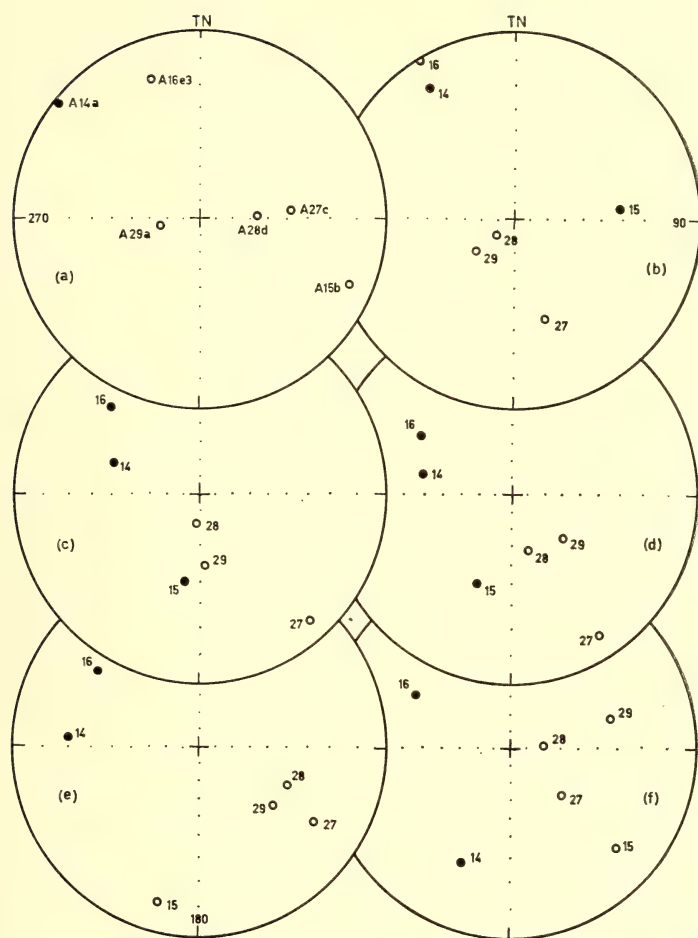


FIG. 11

The changes in the directions of magnetization of the Mt. Tomah pilot specimens (A14a, A15b, A16e3, A27c, A28d and A29a) with treatment in alternating magnetic fields. The directions plotted are:

- (a) N.R.M.'s
- (b) After treatment in 75 oersteds (peak)
- (c) After 150 oe.
- (d) After 300 oe.
- (e) After 450 oe.
- (f) After 600 oe.

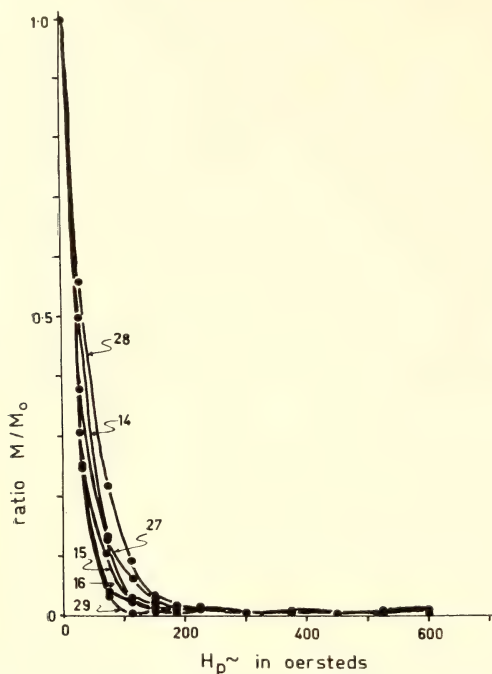


FIG. 12

The variation of the ratio M/M_0 with alternating field strength (H_p) for the Mt. Tomah pilot specimens

but it is clearly not due to viscous components of magnetization or to lightning strikes alone, as these would be removed at least partially by the treatment. It could possibly be due to the original thermo-remanent magnetization decaying away completely with time, leaving only randomly directed magnetizations behind.

Discussion

The directions of magnetization of Luddenham and Peat's Ridge after treatment in an alternating magnetic field of 225 oersteds (peak) are stable, and their average directions may be considered to be coincident with the directions of the geomagnetic field at the time these bodies cooled. For a comparison between these, and for comparison with the results obtained by other workers on similar bodies, pole positions were calculated from these average directions, assuming the earth's field to be a geocentric dipole. A comparison of pole positions eliminates differences caused by differences in the geographic positions of sampling sites. Some error is most probably present in the pole positions calculated, since the secular variation of the earth's field is probably not averaged out in the samples taken, due to the comparative

shortness of the time the bodies would take to cool.

The Luddenham and Peat's Ridge southern hemisphere pole positions are given in Table 3, together with the poles of those rock bodies with which they are compared. Also given in this table are the ages of four of these bodies as determined by radio-isotopic means (McDougall, 1961; Evernden and Richards, 1962). A plot of the pole positions is given in Fig. 13, on an equal-area projection of the earth's southern hemisphere.

By considering the pole positions of Luddenham and Peat's Ridge in relation to the other poles, and considering the geologically and radio-isotopically determined ages, it seems that the dyke at Luddenham is most probably Mesozoic in age, and the intrusion at Peat's Ridge probably Tertiary. It is noteworthy that estimates of ages from previous palaeomagnetic work (e.g. Prospect and Gibraltar) have been proved accurate by subsequent radio-isotopic age determinations. Both Prospect and Gibraltar were estimated as being in the Mesozoic, and radio-isotope work has shown them both to be Jurassic (see Table 3).



FIG. 13

Equal-area stereographic projection of the Earth's southern hemisphere, on which are plotted the pole positions of the rock bodies from south-eastern Australia given in Table 3. The pole positions are numbered as follows:

1. Newer volcanics of Victoria
2. Peat's Ridge dolerite
3. Older volcanics of Victoria
4. Tertiary basalts of N.S.W.
5. Gingenbullen dolerite
6. Cygnet alkaline complex
7. Prospect dolerite
8. Tasmanian dolerites
9. Luddenham dolerite
10. Gibraltar syenite

TABLE 3

Comparison of the palaeomagnetic pole positions and geological ages of igneous rock bodies of south-eastern Australia

References :

1. Boesen, Irving and Robertson (1961)
2. Irving (1963)
3. Irving and Green (1957)
4. Irving, Stott and Ward (1961)
5. Robertson and Hastie (1962)
6. Robertson (1963)

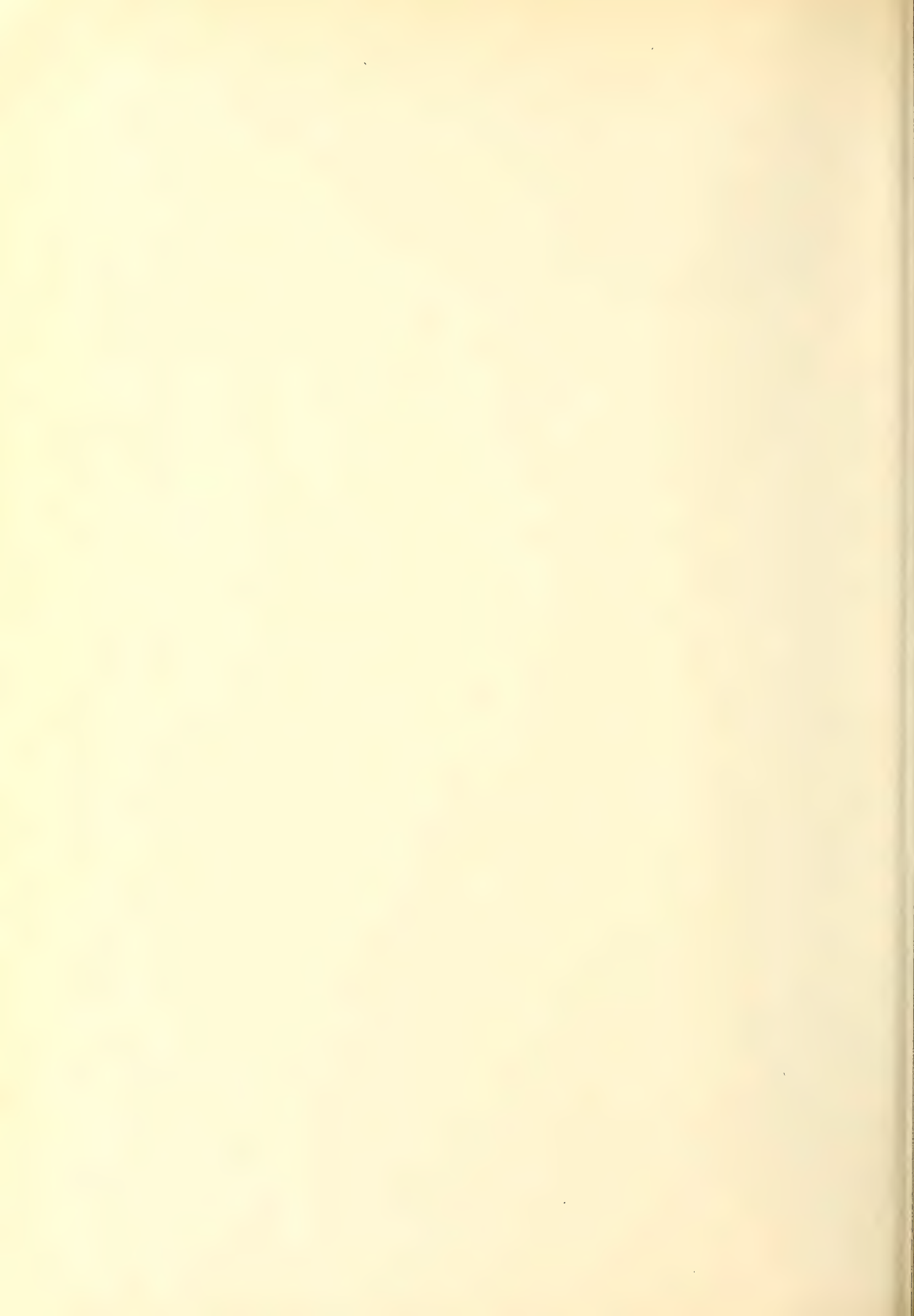
The radio-isotopic age of the Tasmanian dolerites is taken from McDougall (1961), and the rest from Evernden and Richards (1962)

Rock Unit	Ref.	Geological Age	Pole Position	Radio-isotopic Age in millions of years
Gibraltar Syenite	1	post-Upper Triassic	41S, 146E	178 Lower Jurassic
Luddenham Dolerite		post-Upper Triassic	47S, 173E	
Tasmanian Dolerite	2	post-Upper Triassic and pre-Tertiary	51S, 160E	167 Middle Jurassic
Prospect Dolerite	1	post-Upper Triassic	51S, 151E	168 Middle Jurassic
Cygnets Complex	5	post-Tasmanian Dolerites	50S, 158E	104 Lower Cretaceous
Gingenbullen Dolerite	1	post-Upper Triassic	53S, 144E	
Mt. Dromedary Complex	6	post-Permian	56S, 138E	Middle Cretaceous 93
Tertiary Basalts of N.S.W.	4	Tertiary	63S, 137E	
Older Volcanics of Victoria	3	Lower Tertiary	67S, 123E	
Peat's Ridge Dolerite		post-Middle Triassic	70S, 134E	
Newer Volcanics of Victoria	3	Pliocene to Recent	86S, 102E	

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On Mellin Transforms of Functions Analytic in the Neighbourhood of the Origin

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1.

The Mellin transform we will use will be that defined in Titchmarsh, 1948, Th. 71. With a slight modification of the notation we have:

If $f(x)$ belongs to $L^2(0, \infty)$, then

$$(1) \quad \varphi(s, a) = \int_{1/a}^a x^{s-1} f(x) dx, \quad (s = \frac{1}{2} + it)$$

converges in the mean square over $(-\infty, \infty)$ as $a \rightarrow \infty$ to $\varphi(s)$ (say), the Mellin transform of $f(x)$. Also

$$(2) \quad f(x, a) = (1/2\pi) \int_{-a}^a x^{-s} \varphi(s) dt$$

converges in the mean square over $(0, \infty)$ to $f(x)$ almost everywhere. In addition the Parseval formula

$$(3) \quad \int_0^\infty |f(x)|^2 dx = (1/2\pi) \int_{-\infty}^\infty |\varphi(\frac{1}{2} + it)|^2 dt$$

holds.

The Paley-Wiener Theorem (Boas, 1954, p. 103) can be written in the form

The entire function $\varphi(w)$ is of exponential type a and belongs to L^2 on the real axis, if and only if

$$(4) \quad \varphi(w) = \int_{e^{-a}}^{e^a} x^{w-1} f(x) dx$$

where $f(x)$ belongs to $L^2(e^{-a}, e^a)$.

In this modified form the Paley-Wiener Theorem states a necessary and sufficient condition for a function to have a Mellin image which is an entire function of exponential type a .

This suggests that we should examine the Mellin transform of an entire function. However, it will be found profitable to assume that $f(x)$ is analytic only in a neighbourhood of the origin.

1.

In this section we will prove the theorem.

Theorem A

In order that

$$(a) \quad f(x) = \sum_{n=0}^{\infty} a_n x^n, \quad x < R \text{ and that}$$

$$(b) \quad f(x) \text{ belongs to } L^2(0, \infty)$$

it is necessary and sufficient that there should exist a $\varphi(w)$ with the following properties:

(i) $\varphi(w)$ is meromorphic in the half plane $\operatorname{Re} w < \frac{1}{2}$;

(ii) the poles of $\varphi(w)$ in $\operatorname{Re} w < \frac{1}{2}$ are all simple and can only lie at the points $w = -n$ ($n=0, 1, 2, \dots$) with residue a_n ;

- (iii) $\varphi(w) = \varphi(u+it)$ as a function of t belongs to $L^2(-\infty, \infty)$ for $0 < u < \frac{1}{2}$, and $\varphi(u+it) \rightarrow 0$ as $|t| \rightarrow \infty$;
 (iv) $\varphi(s-\alpha) \rightarrow \varphi(s)$ in the mean square as $\alpha \rightarrow 0+$, where $s = \frac{1}{2} + it$;
 (v) In $\text{Re } w < 0$ when $w = (m + \frac{1}{2})e^{i\theta}$,

$$|\varphi(w)| = \begin{cases} r^{\text{Re } w} o(1), & |\pi - \theta| > \varepsilon \\ r^{\text{Re } w} O(1), & |\pi - \theta| < \varepsilon \end{cases} \quad \text{for all } r < R$$

uniformly in θ as $|w| \rightarrow \infty$, where ε may be chosen arbitrarily small;

Proof

We note immediately that in order for the theorem to be meaningful

$$(5) \quad \lim_{n \rightarrow \infty} |a_n|^{-1/n} < R.$$

Assumption (a) immediately implies that $f(x)$ is bounded in a neighbourhood of the origin. Thus $x^{-\alpha}f(x)$ belongs to $L^2(0, \infty)$ for $0 < \alpha < \frac{1}{2}$ and further the integral $\int_0^\infty x^{s-1}f(x)dx$ requires only the limit in mean at the upper end. Additionally

$$(6) \quad \begin{aligned} \varphi(s-\alpha) &= \int_0^\infty x^{s-\alpha-1}f(x)dx \\ &= \int_0^\infty x^{s-1}x^{-\alpha}f(x)dx \end{aligned}$$

exists as an L^2 -integral for $0 \leq \alpha < \frac{1}{2}$ and as an L^1 -integral for $0 < \alpha < \frac{1}{2}$.

It is immediately obvious that $\varphi(w) = \int_0^\infty x^{w-1}f(x)dx$ is analytic in the strip $0 < \text{Re } w < \frac{1}{2}$.

Also the Riemann-Lebesgue Lemma applied to equation (6) gives

$$(7) \quad \lim_{|t| \rightarrow \infty} \varphi(w) = 0, \quad (w = u + it, \quad 0 < u < \tfrac{1}{2}).$$

We next combine equation (6) with the Parseval formula (3) to obtain

$$(1/2\pi) \int_{-\infty}^\infty |\varphi(s-\alpha) - \varphi(s)|^2 dt = \int_0^\infty (x^{-\alpha} - 1)^2 |f(x)|^2 dx \rightarrow 0$$

as $\alpha \rightarrow 0+$.

We now extend the definition of $f(x)$. Let $f(z) = \sum_{n=0}^\infty a_n z^n$ for $|z| < R$ and $f(z) = f(x)$ when $z = x$ is real and positive. Otherwise let $f(z)$ be arbitrary. Then let $F(w)$ be defined by

$$(8) \quad F(w) = \int z^{w-1}f(z)dz$$

where the contour starts at $+\infty$ on the real axis and remains on the real axis until it reaches the region of analyticity of $f(z)$ (i.e. $|z| < R$) and then passes around the origin in an anti-clockwise direction (for example on the circle radius $r < R$) until it meets the real axis again. It then returns to $+\infty$ keeping to the real axis. The integral exists for all $\text{Re } w < \frac{1}{2}$.

When $0 < \text{Re } w < \frac{1}{2}$

$$\begin{aligned} F(w) &= (-1 + e^{2\pi i w}) \int_0^\infty x^{w-1}f(x)dx \\ &= (-1 + e^{2\pi i w})\varphi(w) \end{aligned}$$

So

$$(9) \quad \varphi(w) = F(w)/(e^{2\pi iw} - 1)$$

is the analytic continuation of $\varphi(w)$ into the half plane $\operatorname{Re} w < \frac{1}{2}$.

Since $F(w)$ is analytic for all w with $\operatorname{Re} w < \frac{1}{2}$, $\varphi(w)$ defined by equation (6) will be analytic in the half plane except possibly for simple poles at $s = -n$ ($n = 0, 1, 2, \dots$).

When $w = -n$, the integrand of $F(w)$ becomes single valued. The integral in (8) may be replaced by $F(w) = \int z^{-n-1} f(z) dz$ where the contour is a circle of radius r . The value is easily seen to be $2\pi i f^{(n)}(0)/n! = 2\pi i a_n$. Thus the residue of $\varphi(w)$ at $w = -n$ is a_n .

We must now show that (v) holds.

Write

$$(10) \quad \varphi_1(w) = \int z^{w-1} f(z) dz / (e^{2\pi iw} - 1)$$

where the contour is the circle of radius $r < R$. Then

$$\begin{aligned} \varphi_1(w) &= \int \sum_{n=0}^{\infty} a_n z^{w+n-1} dz / (e^{2\pi iw} - 1) \\ &= \sum_{n=0}^{\infty} a_n r^{w+n} / (w+n). \end{aligned}$$

Now put $w = (m + \frac{1}{2})e^{i\theta}$, $\operatorname{Re} w < 0$, m a non-negative integer.

Thus

$$|\varphi_1(w)| \leq (r^{(m+\frac{1}{2}) \cos \theta} / (m + \frac{1}{2}) \sin \theta) \sum_{n=0}^{\infty} |a_n| r^n$$

when $|\operatorname{Im} w| < \frac{1}{2}$, $|\pi - \theta| > \varepsilon$,

$$(11a) \quad = r^{(m+\frac{1}{2}) \cos \theta} O(1)$$

as $m \rightarrow \infty$. Also

$$|\varphi_1(w)| \leq 2r^{(m+\frac{1}{2}) \cos \theta} \sum_{n=0}^{\infty} |a_n| r^n$$

when $|\operatorname{Im} w| < \frac{1}{2}$, $|\pi - \theta| < \varepsilon$, which shows that

$$(11b) \quad |\varphi_1(w)| = r^{(m+\frac{1}{2}) \cos \theta} O(1)$$

as $m \rightarrow \infty$, with $|\pi - \theta| < \varepsilon$.

The contribution to $\varphi(w)$ from the remainder of the defining contour reduces to

$$\begin{aligned} \varphi_2(w) &= \int_r^\infty x^{w-1} f(x) dx \\ &= \int_r^\infty x^{|w| \cos \theta} x^{i|w| \sin \theta} (x^{-1} f(x)) dx \end{aligned}$$

which can be broken up into four real integrals, by taking the real and imaginary parts of the last two factors in the integrand. One of these integrals will be

$$\varphi_3(w) = \int_r^\infty x^{|w| \cos \theta} \cos(|w| \sin \theta \log x) (x^{-1} k(x)) dx$$

with $k(x) = \operatorname{Re} f(x)$.

Using a mean value theorem (Titchmarsh, 1939, §12.3)

$$\varphi_3(w) = r^{|w| \cos \theta} \int_r^p \cos(|w| \sin \theta \log x) (x^{-1} k(x)) dx$$

(where p is dependent on $|w|$)

$$=r^{|w| \cos \theta} \int_S^P \cos(|w| y \sin \theta) q(y) dy$$

where $P=\log p$, $S=\log r$, $q(y)=k(e^y)$ and from our previous information $\int_S^\infty |q(y)| dy$ exists.

To show that the integral vanishes in the limit when $\sin \theta \neq 0$, we use a modification of the proof of the Riemann-Lebesgue Lemma as given in Goldberg, 1961, p. 7.

Consider

$$F(w) = \int_S^P e^{i|w|y \sin \theta} q(y) dy.$$

After writing $a = \pi/|w| \sin \theta$, we obtain

$$\begin{aligned} 2F(w) = & - \int_P^{P+a} e^{i|w|y \sin \theta} q(y-a) dy \\ & + \int_{S+a}^P e^{i|w|y \sin \theta} (q(y) - q(y-a)) dy \\ & + \int_S^{S+a} e^{i|w|y \sin \theta} q(y) dy. \end{aligned}$$

Therefore

$$\begin{aligned} 2|F(w)| \leq & \int_P^{P+a} |q(y-a)| dy + \int_{S+a}^P |q(y) - q(y-a)| dy \\ & + \int_S^{S+a} |q(y)| dy \\ & \rightarrow 0 \end{aligned}$$

as $|w| \rightarrow \infty$ (Titchmarsh, 1939, §10.73). Provided that $|\sin \theta| > \varepsilon$, the convergence is uniform with regard to both p and θ .

We have thus proved that when $|\sin \theta| > \varepsilon$,

$$(12a) \quad |\varphi_3(w)| = r^{|w| \cos \theta} O(1)$$

as $|w| \rightarrow \infty$.

When $|\sin \theta| < \varepsilon$, we note that

$$\begin{aligned} (12b) \quad |\varphi_3(w)| & \leq r^{|w| \cos \theta} \int_r^\infty x^{-1} f(x) dx \\ & = r^{|w| \cos \theta} O(1) \end{aligned}$$

as $|w| \rightarrow \infty$.

When we combine the results from equations (11a, b) and (12a, b) we see that (v) holds.

We now suppose that (i)–(v) hold.

Suppose that $0 < \alpha < \beta < \frac{1}{2}$ and define

$$f_1(x, \alpha) = \lim_{n \rightarrow \infty} (1/2\pi) \int_{-n}^n x^{-s} \varphi(s - \alpha) dt$$

and

$$f_2(x, \beta) = \lim_{n \rightarrow \infty} (1/2\pi) \int_{-n}^n x^{-s} \varphi(s - \beta) dt.$$

There will be a subsequence of the $\{n\}$, such that the integrals will converge to the right sides almost everywhere. Denote the elements of this sequence by $\{m\}$. Now consider the integral $\int x^{-w} \varphi(w) dw$ taken around the rectangle with sides $\operatorname{Re} w = \frac{1}{2} - \alpha$, $\operatorname{Re} w = \frac{1}{2} - \beta$, $\operatorname{Im} w = \pm m$. Then let $m \rightarrow \infty$ and use (iii).

There are no singularities inside the contour and the contributions from the upper and lower sides vanish. Thus

$$x^\alpha f_1(x, \alpha) = x^\beta f_2(x, \beta),$$

which shows that for $0 < \alpha < \frac{1}{2}$

$$(13) \quad \lim_{n \rightarrow \infty} (1/2\pi) \int_{-n}^n x^{-s} \varphi(s - \alpha) ds = x^{-\alpha} f_3(x)$$

where $f_3(x)$ is independent of α .

After defining

$$(14) \quad f(x) = \lim_{n \rightarrow \infty} (1/2\pi) \int_{-n}^n x^{-s} \varphi(s) ds$$

and using the Parseval formula, we obtain

$$(1/2\pi) \int_{-\infty}^{\infty} |\varphi(s - \alpha) - \varphi(s)|^2 dt = \int_0^{\infty} |x^{-\alpha} f_3(x) - f(x)|^2 dx.$$

Combining this result with (iv), we find that

$$(15) \quad f_3(x) = f(x)$$

almost everywhere.

Let $I_m(x, \alpha)$ be defined by

$$(16) \quad (2\pi i) I_m(x, \alpha) = \int x^{-w} \varphi(w) dw$$

where the contour consists of the arc of the circle $|w| = m + \frac{1}{2}$, which lies in the half plane $\operatorname{Re} w \leq \frac{1}{2} - \alpha$, and the chord of that circle which lies on the line $\operatorname{Re} w = \frac{1}{2} - \alpha$, $0 < \alpha < \frac{1}{2}$.

A simple application of the residue theory shows that

$$I_m(x, \alpha) = \sum_{n=0}^m a_n x^n.$$

Let I_2 be the contribution to $I_m(x, \alpha)$ from the arc in the second quadrant. Suppose that $x < R$, then

$$\begin{aligned} |2\pi I_2| &\leq (m + \tfrac{1}{2}) \left[\int_{\frac{1}{2}\pi}^{\pi - \varepsilon} + \int_{\pi - \varepsilon}^{\pi} \right] x^{-(m + \frac{1}{2}) \cos \theta} \varphi(w) d\theta \\ &\leq (m + \tfrac{1}{2}) o(1) \int_{\frac{1}{2}\pi}^{\pi - \varepsilon} (x/R)^{-(m + \frac{1}{2}) \cos \theta} d\theta \\ &\quad + (m + \tfrac{1}{2}) O(1) \int_{\pi - \varepsilon}^{\pi} (x/R)^{-(m + \frac{1}{2}) \cos \theta} d\theta. \end{aligned}$$

After changing the variable by $\theta = \frac{1}{2}\pi + \beta$ and using the inequality $\sin \beta \leq 2\beta/\pi$ we find that

$$\begin{aligned} |2\pi I_2| &\leq (m + \tfrac{1}{2}) o(1) \int_0^{\frac{1}{2}\pi - \varepsilon} (x/R)^{2(m + \frac{1}{2})\beta/\pi} d\beta \\ &\quad + (m + \tfrac{1}{2}) O(1) \int_{\frac{1}{2}\pi - \varepsilon}^{\frac{1}{2}\pi} (x/R)^{2(m + \frac{1}{2})\beta/\pi} d\beta. \end{aligned}$$

Direct integration followed by suitable choice of ε will show that as $m \rightarrow \infty$, $I_2 \rightarrow 0$.

An analogous procedure shows that the contribution I_3 from the arc in the third quadrant also vanishes as $m \rightarrow \infty$. By assumption (iii) the contribution from the arcs of the circle between $\operatorname{Re} w = 0$ and $\operatorname{Re} w = \frac{1}{2} - \alpha$ also vanishes as $m \rightarrow \infty$.

Hence

$$(17) \quad \lim_{m \rightarrow \infty} (1/2\pi) \int_{-m}^m x^{-s+\alpha} \varphi(s-\alpha) dt = \sum_{n=0}^{\infty} a_n x^n.$$

But we know from our results consequent on equation (16) that if we restrict x to lie between 0 and R , then

$$\text{l.i.m.}_{m \rightarrow \infty} (1/2\pi) \int_{-m}^m x^{-s} \varphi(s-\alpha) dt = x^{-\alpha} f(x).$$

Thus when $x < R$

$$(18) \quad f(x) = \sum_{n=0}^{\infty} a_n x^n$$

which was required.

3.

Suppose that in the theorem in Section 2, $f(z)$ were an entire function, i.e. the R in (a) would be replaced by ∞ . It is easily seen that the proof will hold in this case. So we have

Corollary

The Theorem A of Section 2 holds when all reference to R is deleted.

4.

This section will show a situation in which the Mellin transform is continued to the right. By a simple change of variable we see that

$$\begin{aligned} \varphi(s) &= \text{l.i.m.}_{a \rightarrow \infty} \int_{1/a}^a x^s {}^{-1}f(x) dx \\ &= \text{l.i.m.}_{a \rightarrow \infty} \int_{1/a}^a x^{-s} (x^{-1}f(1/x)) dx \end{aligned}$$

Then noting that $1-s = \frac{1}{2} - it$,

$$(19) \quad \varphi_1(s) = \text{l.i.m.}_{a \rightarrow \infty} \int_{1/a}^a x^s {}^{-1}(x^{-1}f(1/x)) dx.$$

where

$$(19a) \quad \varphi_1(s) = \varphi(1-s).$$

Also

$$(20) \quad \int_0^{\infty} |f(x)|^2 dx = \int_0^{\infty} |x^{-1}f(1/x)|^2 dx.$$

We further assume that $f(x)$ is analytic at ∞ , that is to say

$$(21) \quad f(x) = \sum_{n=0}^{\infty} b_n x^{-n-1}, \quad x > 1/U,$$

which means that

$$(21a) \quad x^{-1}f(1/x) = \sum_{n=0}^{\infty} b_n x^n, \quad x < U.$$

The following modification Theorem A in Section 2 is then obvious.

Theorem B

In order that

(a) $f(x) = \sum_{n=0}^{\infty} b_n x^{-n-1}$, $x > 1/U$ and that

(b) $f(x)$ belongs to $L^2(0, \infty)$,

it is necessary and sufficient that there should exist a $\varphi(w)$ with the following properties :

- (i) $\varphi(w)$ is meromorphic in the half plane $\operatorname{Re} w > \frac{1}{2}$;
- (ii) the poles of $\varphi(w)$ in $\operatorname{Re} w > \frac{1}{2}$ are all simple and can only lie at the points $w = n$ ($n = 1, 2, \dots$) with residue $-b_{n+1}$;
- (iii) $\varphi(w) = \varphi(u + it)$ as a function of t belongs to $L^2(-\infty, \infty)$ for $\frac{1}{2} < u < 1$, and $\varphi(u + it) \rightarrow 0$ as $|t| \rightarrow \infty$;
- (iv) $\varphi(s + \infty) \rightarrow \varphi(s)$ in the mean square as $\alpha \rightarrow 0+$, where $s = \frac{1}{2} + it$;
- (v) In $\operatorname{Re} w > 1$ when $w = 1 + (m + \frac{1}{2})e^{i\theta}$,

$$|\varphi(w)| = \begin{cases} u^{-\operatorname{Re} w} O(1), & |\theta| > \varepsilon \\ u^{-\operatorname{Re} w} O(1), & |\theta| < \varepsilon \end{cases} \quad \text{for all } u < U$$

uniformly in θ as $|w| \rightarrow \infty$, where ε may be chosen arbitrarily small;

(vi) $\varphi(s)$ is the Mellin transform of $f(x)$.

We close this section with the note that if $f(x)$ is analytic in a neighbourhood of the origin and a neighbourhood of ∞ , as well as belonging to L^2 on the x -axis. Then

$$\varphi(x) = \left[\int_0^R + \int_R^{1/U} + \int_{1/U}^{\infty} \right] x^{w-1} f(x) dx$$

is analytic in the strip $0 < \operatorname{Re} w < 1$, and the parts of $\varphi(w)$ in the half planes are analytic continuations of each other.

5.

We now revert to the $f(x)$ defined in Section 2. Write

$$f(x) = f_1(x) + f_2(x)$$

where $f_1(x) = 0$, for $x > R$ and $f_2(x) = 0$ for $x < R$. Then let $\varphi_1(s)$ and $\varphi_2(s)$ be the Mellin transforms of $f_1(x)$ and $f_2(x)$ respectively.

It is immediate that $\varphi_2(w)$ is analytic for all $\operatorname{Re} w < \frac{1}{2}$ and that for all $\beta > 0$, $\varphi_2(s - \beta)$ is the Mellin transform of $x^{-\beta} f_2(x)$.

From what has been said at the end of Section 4, $\varphi_1(w)$ is analytic along a strip enclosing the line $\operatorname{Re} w = \frac{1}{2}$. It is also obvious that $x^{-\frac{1}{2}} f_1(x)$ belongs to $L^1(0, \infty)$. We can then simplify the work by using the L^1 -theory (Titchmarsh, 1937, Th. 28), that is to say, by using

$$\lim_{n \rightarrow \infty} (1/2\pi) \int_{-n}^n x^{-s} \varphi(s) ds = f_1(x)$$

(except possibly when $x = R$).

Take the integral $(1/2\pi i) \int x^{-w} \varphi(w) dw$ around the rectangle with sides $\operatorname{Re} w = \frac{1}{2} - \beta$ ($m + \frac{1}{2} < \beta < m + 1\frac{1}{2}$), $\operatorname{Re} w = \frac{1}{2}$, $\operatorname{Re} w = \pm n$. Then use (iii) and (v) to show that

$$\lim_{n \rightarrow \infty} (1/2\pi) \int_{-n}^n x^{-s+\beta} \varphi(s-\beta) ds = f_1(x) - \sum_{n=0}^m a_n x^n.$$

In other words, the Mellin transform of $x^{-\beta}(f_1(x) - \sum_{n=0}^m a_n x^n)$ is $\varphi(s - \beta)$. Combining the results for $f_1(x)$ and $f_2(x)$ we obtain the

Corollary

If $f(x)$ satisfies the assumptions of the theorem in Section 2, then for $m+\frac{1}{2}<\beta<m+1\frac{1}{2}$, $\varphi(s-\beta)$ is the Mellin transform of $x^{-\beta}(f(x)-\sum_{n=0}^m a_n x^n)$.

This result not only indicates the misleading nature of formula 3, p. 307, of Erdelyi (1954), but also suggests a Mellin treatment of the flattened transforms (Duffin and Schaeffer, 1960).

We can prove an analogous corollary for the case when $f(x)$ is analytic at infinity. The result is

Corollary

If $f(x)$ satisfies the assumption of the Theorem B in Section 4, then for $m+\frac{1}{2}<\beta<m+1\frac{1}{2}$, $\varphi(s+\beta)$ is the Mellin transform of $x^{\beta}(f(x)-\sum_{n=0}^m b_n x^{-n-1})$.

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(Received 9 April 1962)

The Nature of Light Propagation

J. E. ROMAIN

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In a series of three papers published in this Journal, S. J. Prokhovnik (1960, 1961) has proposed an unconventional approach to the problem of length and time measurements in inertial frames. His argument leads namely to "the inequality of the out and return paths of a light-ray travelling between observers in relative motion". He concludes his third paper, going by the same title as above, by stating that special relativity involves a contradiction in that respect, and that only his system is free of such a contradiction.

Although I do not wish to discuss Prokhovnik's general argument, I would like to make it clear that the alleged contradiction is not present in special relativity. Indeed, Figs. 2 and 3 in

Prokhovnik's third paper are inconclusive because they disregard the difference between the time setups in the two inertial frames, as expressed by the Lorentz transformation. The proper graphic way to describe motion phenomena in special relativity is by a space-time diagram.

The attached figure is the relevant space-time diagram that should replace Prokhovnik's Fig. 2; t_A^i and t_B^i mean the times, as measured from A's and B's systems, of the successive reflections R^i of the light ray on two perfect mirrors A and B in relative uniform motion in the direction of propagation of the light ray. The following equalities appear immediately:

$$t_A^2 - t_A^1 = t_A^3 - t_A^2; t_A^4 - t_A^3 = t_A^5 - t_A^4; \dots$$
$$t_B^3 - t_B^2 = t_B^4 - t_B^3; t_B^5 - t_B^4 = t_B^6 - t_B^5; \dots$$

Likewise, the out and return paths R^1R^2 and R^2R^3 , or R^3R^4 and R^4R^5 , are equal when measured from A's reference frame, while the paths R^2R^3 and R^3R^4 , etc., are equal for B. But the latter paths are not equal for A, and indeed no one would expect them to be.

The same diagram also replaces Prokhovnik's Fig. 3 because it actually puts both observers on the same footing since, as is well known, the actual perpendicularity of space and time axes in a Minkowski diagram is physically meaningless; the only meaningful property (Minkowskian orthogonality) is that the x_A - and t_A -axes are conjugate with respect to the light cone, as are the x_B - and t_B -axes.

A similar diagram can be sketched from the point of view of a third observer, with respect to which A and B have equal and opposite velocities. It would be similar to Prokhovnik's Fig. 1, tilted 90° counterclockwise. But the times of reflection would be the squares of those shown by that author. That suggests another experimental check of Prokhovnik's system against the conventional special relativity.

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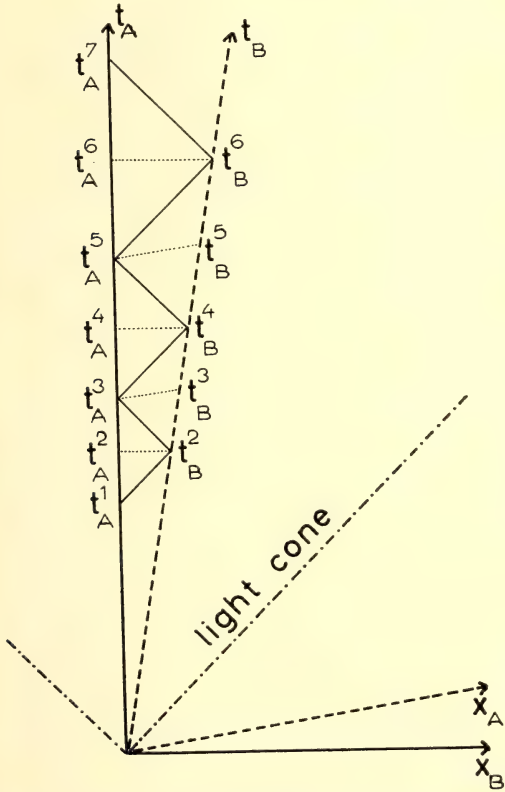


FIG. 1. (Note: The axes labelled x_A and x_B should be interchanged)

(Received 18 June 1962)

Annual Reports by the President and the Council

PRESENTED AT THE ANNUAL MEETING OF THE SOCIETY, APRIL 4, 1962

The President's Report

The activities of the year have been described in the Council's statement. There are a few personal comments I wish to add.

Firstly, in comparison with 1947—when I joined this Society—finances, and attendances at meetings, are now much healthier. We certainly should thank our Treasurer, his predecessors and previous Councils for avoiding the bankruptcy which seemed inevitable 14 years ago.

Regarding attendances, the average per meeting is gratifying from one point of view. Numerically it represents about a fifth of the membership, but we must remember that a considerable number of guests and visitors, who are non-members, are included in the monthly attendance figures. During 1961, you approved certain amendments to our Rules whereby Associates and Students could join us at reduced annual subscriptions. I invite non-members present tonight to consider whether they could not take advantage of these changes, and I ask members to give the Society their strongest support in recruitment to all the grades.

Secondly, it seems to me that the future role of this Society is today much clearer than formerly. Is it not to be a common meeting ground for scientists and other thoughtful people from all disciplines? Specialist bodies now exist and cater for their own specialists. Could not one aim be explicitly to become the "Royal Institution" of Sydney? No such centre for general lectures—"popular science" lectures in the best sense of the word—has yet emerged in Sydney. Here, I submit, is an opportunity for the R.S.N.S.W.

Following this thought, I hope that future Councils will consider the appropriateness of our continuing to maintain the Library and *Journal* in their present forms, now that other libraries have grown up in this city and that other specialist journals exist in Australia. Both these activities are heavy monetary drains and prevent us lowering our subscriptions.

The *Journal* particularly is unattractive in its contents already to many members, and to non-members it cannot appear as an inducement to join us. Having witnessed the recent death of the "Australian Scientist", I wonder whether it would not be a service to science for us to contemplate filling the gap by printing all lectures given before the Society, and attempting to sell the *Journal* in the open market at a price suitably calculated to make membership with receipt of the *Journal* financially worthwhile?

Thirdly, I want to express gratitude to Mr. H. A. J. Donegan (immediate Past President), to Mr. J. L. Griffith, Dr. A. A. Day, Mr. C. L. Adamson, Mr. W. H. G. Poggendorff, and all of the Council, for the generous and self-sacrificing ways they have devoted their times and energies to the Society during the past year, and for the help and kindnesses they have given me personally. Every officer knows that behind the scenes is Miss M. Ogle, and I am only one more President

that has learned that he can depend on her experience, knowledge, and action at all times; it is a pleasure to make this public acknowledgment.

R. J. W. LE FEVRE,
President.

Report of the Council for the Year Ended 31st March, 1962

Presented at the Annual and General Monthly Meeting of the Society held 4th April, 1962, in accordance with Rule XXVI.

At the end of the period under review the composition of the *membership* was 348 members, 21 associate members and 9 honorary members; 38 new members were elected (28 being members of the New England Branch) and two members were reinstated. Eight members and one associate member resigned and two names were removed from the list of members under Rule XVIII.

It is with extreme regret that we announce the loss by death of three very senior members of the Society:

Mr. A. E. Stephen (elected 1916),
Mr. R. Vicars (elected 1920),
Mr. M. F. Albert (elected 1935).

At the General Monthly Meeting held 2nd August, motions regarding alterations to the Rules of the Society were adopted. Such alterations dealt mainly with categories of membership. The full text of the motions is contained in the Abstract of Proceedings of the meeting held on 6th September.

Nine monthly *meetings* were held. The abstracts of all addresses have been printed on the notice papers. The proceedings of these meetings will appear later in the issue of the "Journal and Proceedings". The members of the Council wish to express their sincere thanks and appreciation to the eight speakers who contributed to the success of these meetings, the attendances at which were most gratifying, the average being 62.

The Annual Social Function was held on 20th March at the Sydney University Staff Club and was attended by 60 members and guests.

The Council has approved of the following awards:

The *Clarke Medal* for 1962 (for Zoology) to Professor H. Waring, D.Sc., F.A.A., of Western Australia.

The *Society's Medal* for 1961 to Dr. A. Bolliger of Sydney University.

The *James Cook Medal* for 1961 to Sir John Eccles, Kt., D.Phil., F.R.S., F.A.A., of Canberra.

The *Edgeworth David Medal* for 1961 to Dr. R. O. Slatyer of Canberra.

The *Archibald D. Ollé Prize* to Professor V. A. Bailey, D.Phil., F.A.A.

The *Clarke Memorial Lecture* for 1961 entitled "Our Permian Heritage in Central-Eastern New South Wales" was delivered by Dr. J. A. Dulhunty, of the

Geology Department, University of Sydney. This lecture will be published in a forthcoming issue of the "Journal and Proceedings".

The Society has again received a grant from the Government of New South Wales, the amount being £750. The Government's interest in the work of the Society is much appreciated.

The Society's *financial statement* shows a deficit of £195 13s. 8d. The deficit was due in some measure to a large decrease in the returns from Science House.

The *New England Branch* of the Society met six times during the year and the proceedings of the Branch follow.

Mr. H. A. J. Donegan represented the President at the Commemoration of the Landing of Captain Cook at Kurnell and at the Official Opening of the New Laboratories of the Division of Science Services of the Department of Agriculture, Rydalmere.

The President attended the Annual Meeting of the Board of Visitors of the Sydney Observatory and the Official Opening of the Stony Range Floral Reserve.

On 27th July, the President and the Honorary Secretary waited on His Excellency the Governor of New South Wales.

The President and the Honorary Secretary were present at the ceremony held in the Mitchell and Dixon Libraries on 15th February to mark the publication of the *Journal* of Sir Joseph Banks. They also represented the Society at the Official Opening of the Medical/Health Physics Building at the Australian Atomic Energy Commission Research Establishment at Lucas Heights on 23rd March.

We congratulate Professor Elkin, who has been awarded the first Herbert E. Gregory Medal by the Bernice P. Bishop Museum, Honolulu. He has also been made the first Honorary Life Member of the Pacific Science Association.

We also congratulate Professor K. E. Bullen, F.R.S., F.A.A., on the award of the William Bowie Medal of the American Geophysical Union and the American Meteorological Society.

The Society's representatives on the *Science House Management Committee* were Mr. H. A. J. Donegan and Mr. C. L. Adamson.

Seven parts of the "*Journal and Proceedings*" have been published during the year. These parts contain 28 papers. In the volume just completed (Vol. 95) 23 papers were published. The numbers for previous volumes were: Vol. 91 (1957-8), 19; 92, 23; 93, 15; 94, 16. Average yearly numbers of papers published for five yearly periods since Volume 51 (1917) have been:

1917-1922 ..	20.4	1942-1947 ..	26.0
1922-1927 ..	27.0	1947-1952 ..	34.6
1927-1932 ..	20.0	1952-1957 ..	19.2
1932-1937 ..	27.8	1957-1962 ..	19.2
1937-1942 ..	32.4		

Total over 45 years : 1,133 papers.

Circulation (in round figures): Exchange, 400; Members, 360; subscriptions, 90.

The order of cost of publication for papers in the main fields we have covered lately has been:

Mathematics	£40-60	Chemistry	£50-100
Astronomy	£10-30	Geology	£80-200
Physics	£40-70	Geophysics	£20-60
Relativity	£30-50.		

The *Section of Geology* held five meetings, and abstracts of the proceedings will be published later.

Council held eleven ordinary meetings and attendance was as follows: Prof. R. J. W. Le Fevre 9; Mr. H. A. J. Donegan 8; Mr. A. F. A. Harper 10; Mrs. K. M. Sherrard 9; Mr. Harley Wood 7; Mr. J. L. Griffith 11; Dr. Alan A. Day 10; Mr. C. L. Adamson 9; Dr. Ida A. Browne 10; Father A. G. Fynn 8; Dr. N. A. Gibson 6; Mr. J. W. Humphries 9; Dr. A. H. Low 2; Dr. P. D. F. Murray 1; Mr. W. H. G. Poggendorf 9; Mr. G. H. Slade 5; A/Prof. W. B. Smith-White 9; Mr. N. W. West 8.

The *Library*. Periodicals were received by exchange from 399 societies and institutions. In addition the amount of £101 was expended on the purchase of 11 periodicals.

During the year Mrs. R. Huntley resigned from the position of Assistant Librarian. She has been replaced by Mr. A. F. Day, who commenced duty on 26th March.

Among the institutions which made use of the library through the inter-library loan scheme were:

N.S.W. Govt. Depts—Department of Agriculture, Botanic Gardens, Conservation Department, Joint Coal Board, Forestry Commission, Department of Health, Soil Conservation Service, Sydney County Council, Maritime Services Board, M.W.S. & D. Board, Division of Wood Technology.

Commonwealth Govt. Depts—C.S.I.R.O. Library, Canberra; Chemical Research Laboratories, Melbourne; Coal Research Section, Sydney; Division of Food Preservation, Ryde; Division of Plant Industry, Canberra; Division of Protein Chemistry, Victoria; National Standards Laboratory, Sydney; Division of Animal Physiology, Prospect; Division of Textile Physics, Ryde; Division of Tropical Pastures, Brisbane; Australian Atomic Energy Commission; Commonwealth Acoustics Laboratory; Commonwealth Department of Works; Forestry and Timber Bureau; Department of Civil Aviation; Commonwealth Office of Education; Postmaster-General Engineering Library.

Universities and Colleges—Sydney Technical College; Newcastle University College; Australian National University; University of Sydney; University of New England; University of New South Wales; University of Queensland; Waite Agricultural Research Institute, University of Adelaide; University of Tasmania; University of Western Australia.

Companies—Australian Consolidated Industries; Austral Bronze Co. Ltd.; A.W.A. Ltd.; Lewis Bergers; B.H.P. Co. Ltd.; Wm. Cooper & Nephews; C.S.R. Co. Ltd.; James Hardie & Co. Ltd.; Johnson & Johnson; Lysaght Ltd.; Mauri Bros. & Thomson Pty. Ltd.; Mount Isa Mines Ltd.; Parke Davis & Co. Ltd.; Polymer Corporation; Reichhold Chemicals; S.T.C. Ltd.; Unilever Ltd.; Union Carbide Co. Ltd.; W. D. & H. O. Wills Ltd.

Research Institute—N.S.W. Cancer Council.

Museums and Public Libraries—The Australian Museum; W.A. Library Board.

J. L. GRIFFITH,
Honorary Secretary.

The Honorary Treasurer's Report

The Society this year has recorded a deficit of £195 13s. 8d.

As the publication of a short report from the Honorary Treasurer is a new departure it might be well to review the state of the Society's finances over the past ten years. In 1952 the deficit was £736 and the assets £31,922. Since that year there have been

two years which recorded surpluses and, in general, the deficits have been at a much reduced rate so that from the lowest recorded value of assets in 1955 of £31,067 they have now risen to £31,868—almost the figure of 1952.

Some details of this year's balance sheet might be mentioned.

Certain changes have been made in the form of presentation of the Journal expenditure and revenue. These aspects have been consolidated as shown, so that the actual cost of the Journal is now readily seen in the expenditure column.

It might also be mentioned that last year another change was made. This was in the presentation of

Science House accounts. In previous years the income from Science House was expressed as a surplus after deduction of the Society's rent. In 1961 the Society's share of income appeared in the income account while all rents paid appeared in the expenditure account. This is the reason for the large apparent discrepancies between the 1960 and 1961 figures.

This is the first year for some time that there has been no income from sale of unwanted material from the library and also no publication grant from any source was received. Last year income from these combined sources amounted to £349.

C. L. ADAMSON,
Hon. Treasurer.

Financial Statement

BALANCE SHEET AS AT 28th FEBRUARY, 1962

LIABILITIES		£	s.	d.	£	s.	d.
1961							
42	Subscriptions Paid in Advance				33	1	6
167	Life Members' Subscriptions — Amount carried forward				104	2	0
	Trust and Monograph Capital Funds (detailed below)—						
	Clarke Memorial	1,942	2	2			
	Walter Burfitt Prize	1,170	8	7			
	Liversidge Bequest	736	4	5			
	Monograph Capital Fund	4,562	6	11			
	Ollé Bequest	169	7	1			
8,324					8,580	9	2
23,211	Accumulated Funds				23,021	14	3
100	Employees' Long Service Leave Fund Provision ..				129	10	0
	Contingent Liability (in connection with Perpetual Lease).						
<u>£31,844</u>					<u>£31,868</u>	<u>16</u>	<u>11</u>
ASSETS							
998	Cash at Bank and in Hand				1,019	5	5
	Investments—						
	Commonwealth Bonds and Inscribed Stock—						
	At Face Value—held for:						
	Clarke Memorial Fund	1,800	0	0			
	Walter Burfitt Prize Fund	1,000	0	0			
	Liversidge Bequest	700	0	0			
	Monograph Capital Fund	3,000	0	0			
	General Purposes	1,960	0	0			
8,460					8,460	0	0
100	Fixed Deposit—Long Service Leave Fund ..				129	10	0
	Debtors for Subscriptions	52	16	0			
	Less Reserve for Bad Debts	52	16	0			
14,835	Science House—One-third Capital Cost				14,835	4	4
6,800	Library—At Valuation				6,800	0	0
	Furniture and Office Equipment—At Cost, less						
634	Depreciation				609	2	8
16	Pictures—At Cost, less Depreciation				14	14	6
1	Lantern—At Cost, less Depreciation				1	0	0
<u>£31,844</u>					<u>£31,868</u>	<u>16</u>	<u>11</u>

TRUST AND MONOGRAPH CAPITAL FUNDS

	Clarke Memorial			Walter Burfitt Prize			Liversidge Bequest			Monograph Capital Fund			Ollé Bequest		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Capital at 28th February, 1962	1,800	0	0	1,000	0	0	700	0	0	3,000	0	0	—		
Revenue—															
Balance at 28th February, 1961	108	10	4	129	3	7	7	7	4	1,421	8	2	157	1	7
Income for twelve months	74	5	4	41	5	0	28	17	1	140	18	9	42	5	6
	182	15	8	170	8	7	36	4	5	1,562	6	11	199	7	1
Less Expenditure ..	40	13	6	—			—			—			30	0	0
Balance at 28th February, 1962	£142	2	2	£170	8	7	£36	4	5	£1,562	6	11	£169	7	1

ACCUMULATED FUNDS

	£	s.	d.	£	s.	d.
Balance at 28th February, 1961	23,211	2	7			
Add—						
Transfer from Provision for Life Members' Subscriptions	55	13	0			
Transfer from Subscriptions Received ..	6	6	0			
	23,273	1	7			
Less—						
Increase in Reserve for Bad Debts ..	11	15	8			
Transfer to Long Service Leave Fund						
Provision	25	0	0			
Bad Debts, Written off	18	18	0			
Deficit for twelve months	195	13	8			
	251	7	4			
	£23,021	14	3			

Auditors' Report

The above Balance Sheet has been prepared from the Books of Account, Accounts and Vouchers of the Royal Society of New South Wales, and is a correct statement of the position of the Society's affairs on 28th February, 1962, as disclosed thereby. We have satisfied ourselves that the Society's Commonwealth Bonds and Inscribed Stock are properly held and registered.

Prudential Building,
39 Martin Place, Sydney,
27th March, 1962.

HORLEY & HORLEY,
Chartered Accountants,
Registered under the Public Accountants
Registration Act 1945, as amended.

(Sgd.) C. L. ADAMSON,
Honorary Treasurer.

INCOME AND EXPENDITURE ACCOUNT

1st MARCH, 1961, to 28th FEBRUARY, 1962

1961										£	s.	d.
—	Advertising									3	11	2
—	Annual Social Function									33	17	2
32	Audit									37	16	0
14	Branches of the Society									41	19	9
109	Cleaning									104	0	0
34	Depreciation									32	16	8
49	Electricity									56	4	0
6	Entertainment									3	0	0
39	Insurance									38	5	0
90	Library Purchases									117	9	1
204	Miscellaneous									151	14	6
214	Postages and Telegrams									123	3	0
	Printing Journal—											
	Vol. 94, Parts 5-6				£675	2	6					
	Binding				28	10	0					
	Vol. 95, Parts 1-4				1,244	14	0					
	Reprints				219	4	8					
	Postages				92	1	4					
	Adjustment—Subscriptions (to Journal)				4	7	0					
									2,263	19	6	
	Less—											
	Sale of Reprints				875	7	2					
	Subscriptions (to Journal)				323	12	8					
	Back Numbers				354	16	6					
	Donation to				4	7	1					
	Refund Postages				8	15	2					
987									1,566	18	7	
167	Printing—General									697	0	11
1,084	Rent—Science House Management									195	16	2
4	Repairs									991	14	6
1,310	Salaries									9	16	0
38	Telephone									1,401	16	6
										41	15	11
£4,381										£4,081	16	4
1961										£	s.	d.
844	Membership Subscriptions									934	10	0
9	Proportion of Life Members' Subscriptions									7	7	0
750	Government Subsidy									750	0	0
2,196	Science House Management—Share of Surplus									2,087	18	10
7	Annual Social Function									—		
87	Interest on General Investments									106	6	10
199	Sale of Periodicals <i>ex</i> the Library									—		
150	Publication Grant									—		
139	Deficit for twelve months									195	13	8
£4,381										£4,081	16	4

Obituary

Michael Francois Albert was elected to membership of the Society in 1935 and was for many years engaged in music publication.

Alfred Ernest Stephen, a member of the Royal Society of New South Wales since 1916, was the son of Ernest Farish Stephen and the grandson of Sir Alfred Stephen, Lieutenant Governor and Chief Justice of New South Wales from 1844 to 1873.

Alfred Ernest Stephen was born in 1879 at Newtown, Sydney. He was educated at Sydney Grammar School and trained as an analytical chemist at the Sydney Technical College. He assayed the first samples of phosphate rock to reach Sydney from Nauru and Ocean Island. His interest in the phosphate deposits of the Pacific Islands and Chile continued and he travelled extensively among the Pacific Islands on this business and served in London on a Chilean Nitrate Commission and in Sydney as Manager for Nitrate Propaganda. He was also assayer for Lachlan Goldfields at Forbes and for the Great Cobar Copper Mines in 1907.

Through his mother, he was descended from James Taylor, who first tried to apply steam power to ships at Loch Dalswinton, Ayrshire, in 1788. He also had

wide interests in the early history of Australia and at various times filled the positions of President and Honorary Secretary of the Royal Australian Historical Society. He died on 25th November, 1961.

Robert Vicars was born in Rockhampton, Queensland, in 1867. His parents came from Scotland in the early 1860's.

He was associated with John Vicars & Co. Limited for about 75 years. The company was originally a partnership, and when in 1914 it was converted to a limited liability company he became joint Governing Director with his brother Sir William Vicars. This continued until the death of Sir William in 1940, and Robert Vicars remained Governing Director until 1947, when he relinquished that position but remained a Director of the company until his death.

He was for a number of years a Director of the Commercial Banking Company of Sydney Limited, Bonds Industries Ltd., and Carpet Manufacturers Ltd.

Outside his business he was Trustee of Sydney Grammar School and a member of the Councils of the Presbyterian Ladies' Colleges, Croydon and Pymble. He was elected to membership of the Royal Society of New South Wales in 1921.

Members of the Society, April, 1962

A list of members of the Society up to 1st April, 1961, is included in Volume 95.

During the year ended 31st March, 1962, the following were elected to membership of the Society.

- ANNISON, Ernest Frank, Ph.D., F.R.I.S., Senior Lecturer in Chemical Pathology, School of Rural Sciences, University of New England, Armidale.
- BAGNALL, Mary, M.A. (Melb.), Mary White College, University of New England, Armidale.
- BEAVIS, Margaret, B.Sc., Dip.Ed., 2/94 Beach Street, Coogee.
- BLUNT, Michael Hugh, M.R.C.V.S., Veterinary Surgeon, 185 Markham Street, Armidale.
- BURNS, Bruce Bertram, B.D.S., Dentist, P.O. Box 60, Armidale.
- BUTLAND, Gilbert James, B.A., Ph.D., F.R.G.S., Professor of Geography, University of New England, Armidale.
- COALSTAD, Stanton Ernest, B.Sc., Metallurgical Chemist, 54 Bridge Street, Sydney.
- DAVIS, Gwenda Louise, B.Sc., Ph.D., A/Professor, Department of Botany, University of New England.
- DAVIS, Iain Horwood, Department of Geography, University of New England.
- ENGEL, Brian Adolph, M.Sc., Geology Department, Newcastle University College, Tighe's Hill, 2N.
- FAYLE, Rex Dennes Harris, Dip.Pharmacy, Pharmaceutical Chemist, 141 Jeffrey Street, Armidale.
- FLETCHER, Neville Horner, B.Sc., M.A., Ph.D., Department of Physics, University of New England, Armidale.
- GILES, Edward Thomas, M.Sc., Ph.D., D.I.C., F.R.E.S., Senior Lecturer, Department of Zoology, University of New England, Armidale.
- GRANT, John N. G., Dip.Eng., Billong Court, Billong Avenue, Vaucluse.
- GUTSCHE, Herbert William, B.Sc., Geology Department, University of New England, Armidale.
- IZSAK, Dennis, 5 Ormonde Gardens, Coogee.
- JACKSON, Robert James, M.A. (Q'ld.), M.B., Ch.M. (Syd.), 132 Faulkner Street, Armidale.
- LANDECKER, Kurt, D.Ing. (Berlin), Department of Physics, University of New England.
- LEAVER, Gaynor Eiluned, B.Sc. (Wales), F.G.S. (Lond.), 30 Ingalara Avenue, Wahroonga.
- McCLYMONT, Gordon Lee, B.V.Sc., Ph.D., Professor of Rural Science, University of New England, Armidale.
- McMAHON, Barry Keys, B.Sc., Island Bend, N.S.W.
- MORGAN, Jascha Ann, M.Sc., Department of Zoology, University of New England, Armidale.
- O'FARRELL, Antony Frederick Louis, A.R.C.S., B.Sc., Professor of Zoology, University of New England, Armidale.
- PLUMMER, Brian Alfred George, M.A., F.G.S., Department of Geography, University of New England, Armidale.
- PRIESTLEY, John Henry, M.B., B.S., B.Sc., 137 Dangar Street, Armidale.
- RIGGS, Noel Victor, B.Sc. (Adel.), Ph.D. (Cantab.), F.R.A.C.I., A/Professor of Organic Chemistry, University of New England, Armidale.
- ROBERTS, John, B.Sc.Hons., Geology Department, University of Western Australia, Nedlands.
- ROYLE, Harold George, M.B., B.S. (Syd.), 161 Rusden Street, Armidale.
- RYDER, Michael Lawson, M.Sc., Ph.D., M.I.Biol., 183 Markham Street, Armidale.
- SOURRY, Charles, Zoology Department, University of New England, Armidale.
- SPITZER, Hans, Dr.Phil. (Vienna), Senior Research Chemist, Monsanto Chemicals (Aust.) Ltd., Rozelle, p.r. 35 Redan Street, Mosman.
- STOCK, Alexander, D.Phil., Ph.D., A/Professor of Zoology, University of New England, Armidale.
- STOKES, Robert Harold, Ph.D., D.Sc., F.A.A., 45 Garibaldi Street, Armidale.
- TAYLOR, Nathaniel Wesley, M.Sc. (Syd.), Ph.D. (N.E.), Department of Mathematics, University of New England, Armidale.
- TISHER, Richard Paul, M.Sc., Dip.Ed., Lecturer in Physics, Teachers' College, Armidale.
- WILKINSON, John Frederick George, M.Sc. (Q'ld.), Ph.D. (Cantab.), A/Professor of Geology, University of New England, Armidale.
- WRIGHT, Anthony James, B.Sc., Department of Geology, University of Sydney.
- YEATES, Neil Tolmie McRae, D.Sc.Agr. (Q'ld.), Ph.D. (Cantab.), A/Professor of Livestock Husbandry, University of New England, Armidale.

The following member having returned from abroad was reinstated:

CHURCHWARD, John Gordon, B.Sc.Agr., Ph.D.,
6 Kareela Road, Chatswood.

During the same period resignations were received from the following :

Bolt, Barbara (Associate)
Bunch, Kenneth
Craig, David Parker
Knight, Oscar Le Maistre
Lawrence, Peter

Maze, William Harold
Meggitt, Mervyn John
Reuter, Fritz Henry
Smith, Eric Brian Jeffcoat

and the following names were removed from the list of members under Rule XVIII :
Burrows, Keith Meredith ; Murray, James Kenneth.

Obituary, 1961-62

Alfred Ernest STEPHEN (1916)
Robert VICARS (1920)
Michael Frank ALBERT (1935)

Medals, Memorial Lectureships and Prizes

James Cook Medal

1961 Sir John Eccles, Kt., D.Phil., F.R.S., F.A.A.

Clarke Medal

1962 Horace Waring, D.Sc., F.A.A. (Zoology)

The Society's Medal

1961 Adolph Bolliger, D.Sc. (Biochemistry)

Edgeworth David Medal

1961 Ralph Owen Slatyer, D.Sc.Agr.

Clarke Memorial Lectureship

1961 John Allan Dulhunty, D.Sc.

Archibald D. Ollé Prize

1961 Victor Albert Bailey, D.Phil., F.A.A.

Recipients of Society Awards, 1962

Sir John Carew Eccles, M.B., B.S., M.A., D.Phil., F.R.A.C.P., F.R.S.N.Z., F.A.A., F.R.S., Professor and Head of the Department of Physiology, Australian National University—the James Cook Medal.

For 30 years the main aim of Eccles' work has been to provide a complete account of the processes which occur at the junctions between one nerve cell and another.

Using physical and electronic techniques of great delicacy and refinement, together with imagination, experimental ingenuity, enthusiasm and sustained energy beyond the ordinary, he has made the cellular mechanisms of the neurone accessible to precise analytical study.

His laboratory in Canberra, through its achievements under his inspiration and leadership, has acquired the reputation of being in the forefront of neurophysiological effort in the world.

The researches of Eccles, described in many papers, are summarized in two books, "The Neurophysiological Basis of Mind" (1952) and "The Physiology of Nerve Cells" (1957). They have placed the study of the central nervous system on an entirely new plane.

Professor Horace Waring, F.A.A., Department of Zoology, University of Western Australia—the Clarke Medal.

Professor H. Waring came to Australia in 1949 to the Chair of Zoology in the University of Western Australia. Prior to this, he was Acting Professor of Zoology in the University of Birmingham. Since coming to Australia, he has built up a very active research school in Western Australia, with the emphasis on the physiology and ecology of Australian marsupials. He himself has published a number of outstanding papers on this research, and his associated colleagues have published extensively. I think it can be said that as a result of Professor Waring's enthusiasm, insight and skill, it can no longer be said that Australian zoologists do not study their own distinctive marsupial fauna. The emphasis of the physiological studies has been on nutrition, endocrinology and reproductive physiology. The emphasis of the ecological studies has been an original one of using physiological health as an indicator of environmental stress. The work is centred on the Rottneest Wallaby, but has included quite a wide range of marsupials. The work has brought international acclaim, both to Professor Waring and his school.

Professor Waring has published 39 papers on chromatophores in amphibia and fishes, reproductive physiology and endocrinology (especially the hormones of the posterior lobe of the pituitary) of a variety of vertebrates, nutrition of marsupials and marsupial ecology. He has made a most distinguished contribution to the natural sciences in Australia.

Adolph Bolliger, D.Sc., Director Gordon Craig Research Laboratory, Royal North Shore Hospital, Sydney—the Society's Medal.

Dr. Bolliger has worked as Director of the Gordon Craig Research Laboratory since 1929. During a long and active life in basic research he has investigated many chemical problems, notably those concerned with Keratin Chemistry. To the Royal Society of New South Wales he is perhaps best known for his important contributions to the literature and study of Australian marsupial animals, on some aspects of which he is undoubtedly among the foremost world authorities. He has been a Member of this Society since 1933, has served on its Council, and was President in 1945.

Ralph Owen Slatyer, D.Sc.Agr., C.S.I.R.O., Canberra—the Edgeworth David Medal.

Dr. Slatyer's papers on plant-soil-water relations have provided a more fundamental and dynamic basis for interpreting plant responses to soil and atmospheric stresses. This has led to a more basic understanding of the effects of water stress on plant growth and of the factors affecting the availability of soil water to plants.

Victor Albert Bailey, D.Phil., F.A.A.—the Archibald D. Ollé Prize, which is awarded each year for what is adjudged the best scientific contribution to the Society during the year.

The Ollé Prize has been awarded to Professor V. A. Bailey for his paper entitled "Net Electric Charges on Stars, Galaxies and 'Neutral' Elementary Particles".

In this paper Professor Bailey sets out in detail for the first time a hypothesis of considerable originality which is both stimulating and intriguing with far-reaching implications in astrophysics and cosmology.

Professor Bailey has a long record of major contributions in diverse fields of science and this, his latest contribution, if fully proven, would rank as his most notable.

Abstract of Proceedings, 1961

5th April, 1961

The ninety-fourth Annual and seven hundred and sixty-fourth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. H. A. J. Donegan, was in the chair. Sixty-one members and visitors were present.

Stanton Ernest Coalstad and Barry Keys McMahon were elected members of the Society.

The following awards of the Society were announced :

The Society's Medal for 1960 : Professor T. Griffith Taylor, D.Sc., F.A.A.

The Clarke Medal for 1961 : Mr. C. A. Gardner.

The Edgeworth David Medal for 1960 : Professor R. D. Brown.

The Archibald D. Ollé Prize : Mr. H. G. Golding.

The Annual Report of the Council and the Financial Statement were presented and adopted.

Messrs. Horley & Horley were re-elected as Auditors of the Society for 1961-62.

Office-bearers for 1961-62 were elected as follows :

President : R. J. W. Le Fevre, D.Sc., F.R.S., F.A.A.

Vice-Presidents : H. A. J. Donegan, M.Sc., A. F. A. Harper, M.Sc., Kathleen M. Sherrard, M.Sc., Harley Wood, M.Sc.

Hon. Secretaries : J. L. Griffith, B.A., M.Sc., Alan A. Day, B.Sc. (Syd.), Ph.D. (Cantab.).

Hon. Treasurer : C. L. Adamson, B.Sc.

Members of Council : Ida A. Browne, D.Sc., A. G. Fynn, B.Sc., N. A. Gibson, Ph.D., J. W. Humphries, B.Sc., A. H. Low, M.Sc., P. D. F. Murray, D.Sc., F.A.A., W. H. G. Poggendorff, B.Sc. Agr., G. H. Slade, B.Sc., W. B. Smith-White, M.A., N. W. West, B.Sc.

The retiring President, Mr. H. A. J. Donegan, delivered his Presidential Address entitled "Chemistry and the Mining Industry".

At the conclusion of the meeting the retiring President welcomed Professor R. J. W. Le Fevre, F.R.S., F.A.A., to the Presidential Chair.

3rd May, 1961

The seven hundred and sixty-fifth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor R. J. W. Le Fevre, F.R.S., F.A.A., was in the chair. Fifty-four members and visitors were present.

An address entitled "The Indians of the Andes" was given by Dr. E. R. Tichauer, of the University of New South Wales.

7th June, 1961

The seven hundred and sixty-sixth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor R. J. W. Le Fevre, F.R.S., F.A.A., was in the chair. Forty-two members and visitors were present.

John N. G. Grant, Mary Bagnall, Gilbert James Butland, Herbert William Gutsche, Robert James Jackson, Gordon Lee McClymont, Anthony F. L. O'Farrell, John Henry Priestley, Michael Lawson Ryder, Charles Sourry, and Robert Harold Stokes were elected members of the Society.

It was reported that at its meeting on 5th May the New England Branch had elected the following officers for 1962-63 :

Chairman : Dr. P. D. F. Murray.

Secretary : Dr. R. L. Stanton.

Committee : N. K. Fletcher, J. H. Priestley, M. L. Ryder, N. W. Taylor, R. Tisher.

An address entitled "Advances in Radio Astronomy" was given by Dr. B. Y. Mills, Chatterton Astronomy Department, School of Physics, the University of Sydney. The address was illustrated with slides.

5th July, 1961

The six hundred and sixty-seventh General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor R. J. W. Le Fevre, F.R.S., F.A.A., was in the chair. Forty-five members and visitors were present.

The following were elected members of the Society Iain Horwood Davis, Neville Horner Fletcher, Kurt Landecker, Jascha Ann Morgan, Brian Alfred George Plummer, Noel Victor Riggs, Nathaniel Wesley Taylor.

Notice of Motions : The Hon. Secretary gave notice that at the next General Monthly Meeting the following motions would be put :

1. That Rule 8b should be deleted and replaced by—

8b Council, on the nomination on a prescribed form of certificate of one member of the Society, may admit as an associate a person under twenty-seven (27) years of age who does not desire to receive the Journal and Proceedings.

8c Council, on the nomination of a prescribed form of certificate of one member of the Society, may admit as a junior member (i) an undergraduate attending a course for his/her first degree at a university or technical college, (ii) any other person under twenty-one years of age.

8d Council, on the nomination on a prescribed form of certificate of one member of the Society, may admit as a family member any close relative of an ordinary member.

An associate, junior member or family member shall not be a member. Such persons shall have the privileges of a member except that he/she may not vote, sign the Obligation Book, receive the Journal and Proceedings, or hold executive office.

That Rule 9, subscriptions, paragraph 1, should be replaced by the following : Ordinary membership, £3 3s.; Absentee membership, £2 2s.; Associate fee, £1 1s.; Junior and Family fee, 10s. 6d.

2. That Rule 9, paragraph 2, dealing with life membership, should be deleted and that the subscription for life membership should be determined by a formula which gives the present value of thirty-five annual subscriptions.

An address entitled "Forestry in New South Wales" was delivered by Mr. J. L. Henry, of the Forestry Commission of New South Wales.

2nd August, 1961

The six hundred and sixty-eighth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor R. J. W. Le Fevre, F.R.S., F.A.A., was in the chair. There were present forty members and visitors.

The following were elected members of the Society: Margaret Beavis and Gaynor Eiluned Leaver.

The following motions were carried:

1. That Rule 8b should be replaced by—

8b Council, on a prescribed form of certificate of one member of the Society, may admit as an associate (i) a person under 27 years of age who does not desire to receive the Journal and Proceedings; (ii) an undergraduate attending a course for his/her first degree or its equivalent at a university or technical college; (iii) a close relative of an ordinary member; (iv) any other person under 21 years of age.

An associate shall not be a member. An associate shall have the privileges of a member except that he/she may not vote, sign the Obligation Book, receive the Journal and Proceedings, or hold executive office.

That Rule 9, subscriptions, paragraph 1, should be replaced by the following:

	£	s.	d.
Ordinary membership ..	3	3	0
Absentee membership ..	2	2	0
Associate fees:			
category 1	1	1	0
categories 2, 3 and 4 ..	10	6	

2. That Rule 9, paragraph 2, dealing with Life membership, should be deleted and replaced by—

"The subscription for Life membership shall be determined by a formula which gives the present value of thirty-five annual subscriptions."

An address entitled "Whale Research and its Relation to Whaling" was delivered by Mr. W. H. Dawbin, of the Department of Zoology, the University of Sydney.

6th September, 1961

The six hundred and sixty-ninth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor R. J. W. Le Fevre, F.R.S., F.A.A., was in the chair. There were present 62 members and visitors.

The following were elected members of the Society: Ernest Frank Annison, Michael Hugh Blunt, Bruce

Bertram Burns, Gwenda Louise Davis, Brian Adolph Engel, Rex Dennes Harris Fayle, Edward Thomas Giles, Alexander Stock, Richard Paul Tisher, John Frederick George Wilkinson, Anthony James Wright and Neil Tolmie McRae Yeates.

Alterations to the Rules carried at the meeting held 2nd August, 1961, and quoted in the Proceedings of that meeting, were confirmed.

An address entitled "The Search for New Drugs" was delivered by Professor R. H. Thorp, of the Department of Pharmacology, the University of Sydney.

4th October, 1961

The six hundred and seventieth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor R. J. W. Le Fevre, F.R.S., F.A.A., was in the chair. There were present 75 members and visitors.

Members were informed that there are certain numbers of the Journal and Proceedings of the Society which are now out of print or of which we have only very few copies. These are: Volumes 76, 78, 84, 85, 86, 87, 90, 91. Since overseas and Australian libraries periodically request complete sets of the Journal and Proceedings, it is most regrettable that incomplete sets must be sent.

If members have copies for which they no longer have use, we would be very grateful to have them returned to the Society.

An address entitled "Changing Concepts in Human Cancer" was delivered by Dr. Kenneth W. Starr, Honorary Director, New South Wales State Cancer Council.

1st November, 1961

The six hundred and seventy-first General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor R. J. W. Le Fevre, F.R.S., F.A.A., was in the chair. There were present 100 members and visitors.

The following were elected members of the Society: Dennis Izsak, John Roberts and Hans Spitzer.

An address entitled "Developments in Knowledge of the Planet Earth" was delivered by Professor K. E. Bullen, F.R.S., F.A.A., of the Department of Applied Mathematics, the University of Sydney.

6th December, 1961

The seven hundred and seventy-second General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor R. J. W. Le Fevre, F.R.S., F.A.A., was in the chair. Sixty-five members and visitors were present.

Harold George Royle was elected a member of the Society.

An address entitled "The Evolution of Modern Cardio-Vascular Surgery" was delivered by Mr. Rowan Nicks, of the Royal Prince Alfred Hospital Medical Centre, Newtown.

Annual Report of the New England Branch of the Royal Society of New South Wales

The first meeting of the Branch was held at the University of New England on Friday, 24th March, 1961. Just over 120 people attended and heard the Inaugural Address, "The Planet Earth", delivered by Professor K. E. Bullen, F.R.S.

At a meeting on 5th May, 1961, the first formal business of the Branch was transacted, and the following officers elected:

Chairman: P. D. F. Murray.

Secretary: R. L. Stanton.

Committee: N. H. Fletcher, J. H. Priestly,
M. L. Ryder, N. W. Taylor, R. Tisher.

During the year six meetings were held, as follows:

24th March—Professor K. E. Bullen, F.R.S.: Inaugural Address, "The Planet Earth".

5th May—Associate Professor N. T. M. Yeates: "Seasonal light changes and their effect on animal functions".

22nd May—Sir Rudolph Peters, F.R.S.: "Biochemical lesions".

1st July—Sir Alister Hardy, F.R.S.: "Plankton studies in the North Sea".

29th September—Professor J. M. Somerville: "An outline of research in the Physics Department, University of New England".

17th October—Professor C. T. Watson-Munro: "Prospects of thermo-nuclear power".

The Royal Society of New South Wales New England Branch

Balance Sheet

<i>Particulars</i>	<i>Debit</i>			<i>Credit</i>		
	£	s.	d.	£	s.	d.
Grant, parent Society				25	0	0
Cost of meetings	7	6	3			
Interest on bank account					6	11
Cheque, parent Society				1	1	6
Refund of Assoc. Membership to D. J. Cameron and J. Busbridge	1	1	0			
Exchange			6			
	<hr/>			<hr/>		
	8	7	9	26	8	5
Credit Balance	18	0	8			
	<hr/>			<hr/>		
	£26	8	5	£26	8	5

R. L. STANTON,
Hon. Secretary.

Section of Geology

CHAIRMAN : L. E. Koch, Dr.Phil.Habil. ; HON. SEC. : H. G. Golding, M.Sc., A.R.C.S.

Abstract of Proceedings, 1961

Five meetings were held during the year 1961. Average attendance was 17 members and visitors.

MARCH 17th (Annual Meeting). Election of office-bearers : Dr. L. E. Koch was re-elected Chairman and Mr. H. G. Golding was re-elected Honorary Secretary of the Section.

(1) *Notes and Exhibits* : Professor L. J. Lawrence reported on "blooming in sphalerite". Polished sections of ore from Webb's Silver Mine near Emmaville developed blue-grey patches, believed to be films of goslarite, on exposure. He also showed slides of a recently discovered recumbent anticline or large slump structure, in Hawkesbury Sandstone, at Dobroyd Reserve near Seaforth. Mr. H. G. Golding exhibited fulgurites collected by Mr. G. E. Gabriel and himself south of Port Macquarie, root-concretions from Avalon dunes, and specimens of jaspilites collected by Dr. Markham and himself from the Middleback Ranges, South Australia. Mrs. K. Sherrard paid a tribute to the late Miss Elles and noted the recent discovery of Ordovician graptolites near Parkes.

(2) *Address* : "The Teschenites of Eastern Australia", by Dr. W. R. Browne. Dr. Browne referred to the teschenites which have been noted at intervals from the Ipswich district (Q'ld.) to north-western Tasmania, most known occurrences being in New South Wales. Some intrusions have ultrabasic differentiates and some are accompanied by alkaline syenites. A field-association between the teschenites and early Tertiary alkaline intermediate intrusions and extrusions has been observed, and there is some similarity of composition between syenitic differentiates and the alkaline syenites (like those of Bowral) and trachytes which suggest a co-magmatic relation. On various grounds, such as chemical and mineralogical affinities with known Tertiary rocks, unconformities with Oligocene basalts, etc., the teschenites are tentatively assigned an Eocene age, and because of their association with gently folded strata not younger than Jurassic, the question arises as to whether or not folding and intrusion were synchronous.

MAY 19th : (1) Professor L. J. Lawrence exhibited well-crystallized grossularite overgrowing a grossularite crystal of slightly different crystal habit, the specimen being from Duckmaloi, New South Wales.

(2) *Address* : "The Application of Phase Equilibrium Studies to Problems of Ore Genesis", by Dr. N. L. Markham. Dr. Markham noted that phase equilibrium studies involving metallic sulphides, sulphosalts and related minerals aimed at the elucidation of prevailing temperature-pressure-composition parameters during the formation of sulphide ores, provided evidence as to the extent to which chemical equilibrium has been reached in a natural system, explained the common occurrence of certain mineral assemblages and textures and, ultimately, are of the greatest importance in discussions of ore genesis. The stability field of a sulphide mineral or assemblage may be considered

a function of temperature, pressure and partial pressure of sulphur. The systems Cu-S, Fe-S and Cu-Fe-S were then briefly reviewed. Mutual solubility of one sulphide mineral in another as a function of temperature, the best example being that of the FeS-ZnS system, and high-temperature phase transitions offered the best hope for future advance.

JULY 21st : (1) Dr. L. E. Koch exhibited a pair of Chinese sun-glasses purchased in Shanghai in 1898, consisting of two plane discs of smoky quartz mounted in a metal frame, the former being cut from a crystal in a plane approximately normal to its optic axis, and showing cracks and flaws and a patchy distribution of the brownish pigment.

(2) *Address* : "Fractionation of Tin in Natural Silicate Systems", by Mr. J. Rattigan. Mr. Rattigan, after describing the granites associated with tin in the Australian tin provinces, pointed out that field, petrographic and chemical data show that the "tin granites" are magmatic products. Variation diagrams of the Larson and Nockholds type suggest that only magmas which have fractionated to produce significant volumes of residual magma, corresponding in composition with melts at the thermal minima of the synthetic Q-Or-Ab system, show an association with tin. Reasons for the association of tin with "tin granites" were suggested in terms of the trace content of tin in mineral structures.

SEPTEMBER 15th : (1) *Exhibits* : Dr. W. R. Browne exhibited a specimen of Banded "Billy" or "Greybilly" sent to him by Dr. Jones, probably from the Beaudesert area. The rock probably underlies basalt and the banding suggests a Liesegang effect. Dr. A. Carter exhibited specimens of Tentaculites from Buchan, Victoria, and from "Shearsby's Wallpaper", Taemas, N.S.W. Mr. H. G. Golding exhibited violarite-bearing ore and sulphide-impregnated asbestos from Goobaragandra, N.S.W., serpentinite coated with malachite and chrysocolla on shear planes, and micro-styrolitic picrolite both from the Brungle district, N.S.W., and chromite veined with pink chrome clinocllore and chromite coated with hyalite both from Mount Lightning, N.S.W. Dr. Koch exhibited specimens of shale breccia collected during the excavation for the Warragamba Dam foundation site in 1954, and showing exfoliation of contorted, finely laminated shale fragments, with sand (now lithified to sandstone)—intimately interfingering with the exfoliated shale laminae. He also showed kodachromes of calyx bore cores which have since perished by exfoliation.

(2) *Address* : "The Stratigraphic Value of Two Enigmas : Graptolites and Tentaculites", by Mrs. K. Sherrard. Mrs. Sherrard referred to the value of graptolites and of tentaculites as Index Fossils despite doubt as to their zoological status. Dendroidea found in Poland show a relation to Rhabdopleura as elucidated by Kozłowski. Bulman follows Kozłowski, but some American workers would place the Graptoloidea among the Bryozoa. Tentaculites as well as Hyolithes, Styliolina and Conularia have been placed among the

Pteropoda, but Pteropods are not certainly known before the Mesozoic and differ from Tentaculites in shell characters. Recent French and Russian workers have erected new Molluscan classes to hold Tentaculites, etc. Some workers placed Tentaculites among the Polychaeta, a view supported by the frequent occurrence, in Silurian and Devonian strata, of Scolecodonts. However, present day tube-building worms, excepting Onuphis, do not possess jaws, nor are their tubes so regular as those of Tentaculites.

NOVEMBER 17th : (1) *Note and Exhibit by Dr. Koch* : Dr. Koch spoke of the co-deposition of mica, graphite and plant debris, frequently found together in paper-thin layers, in Hawkesbury Sandstone. A tentative working hypothesis proposed for the co-incident deposition of the above particles invoked the combined action of saltation, flotation by reason of a specific gravity lower than that of water, and the

flotation of flaky minerals due to colloidal clay and organic matter acting as flotation agents. Experiments to test the hypotheses were envisaged.

(2) *Address* : "A Geologist in the Desert", by Dr. F. W. Booker. Dr. Booker spoke on his recent travels in Syria, illustrating his remarks with a series of outstanding colour slides. These included views of the rugged limestone mountain, stony desert and oil-field country, telephotos of snowcapped Lebanon and shots of the Rift Valley System along the Jordan River. He also showed a series of archaeological subjects of exceptional interest including the Roman ruins at Baalbek, various Mohammedan shrines on the sites of former Christian churches, and other famous historical locations.

H. G. GOLDING,
Honorary Secretary,
Section of Geology.

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ERRATA

"The Zonal Distribution of Australian Graptolites", by D. E. Thomas, *Journal and Proceedings of the Royal Society of New South Wales*, Volume 94, Part 1, 1960, pp. 1-58

Page 1, column 2, line 8:

For "*Archaeolafoeia*", read "*Archaeolafoea*".

Page 15, near bottom column 1:

For "Samphire No. 1 Bore", read "Goldwyer No. 1 Bore".

For "Goldwyer No. 1 Bore", read "Samphire No. 1 Bore".

Page 21, Literature Cited:

In Harris and Thomas, 1955, reference should read *Ibid.*, 5, part 5, p. 35.

Page 39, Bibliography references:

No. 153 should read *Min. and Geol. J. Vic.*, 1, pt. 1, pp. 64-67.

No. 155 should read *Min. and Geol. J. Vic.*, 1, pt. 2, pp. 70-81.

No. 157 should read *Min. and Geol. J. Vic.*, 1, pt. 3, pp. 62-72.

Page 40, Bibliography references:

No. 176 should read *Min. and Geol. J. Vic.*, 3, pt. 3, p. 43.

No. 178 should read *Min. and Geol. J. Vic.*, 3, pt. 5, p. 52.

No. 186 should read *J. Proc. Roy. Soc. N.S.W.*, 85, p. 127.

No. 191 should read *Min. and Geol. J. Vic.*, 5, pt. 3, p. 34.

No. 192 should read *J. Proc. Roy. Soc. N.S.W.*, 87, p. 73.

No. 194 should read *Min. and Geol. J. Vic.*, 5, pt. 6, p. 35.

Page 40, Explanation of Plates:

Fig. 1.— $\times 1$ should read $\times 2$.

Fig. 9.— $\times 1$ should read $\times \frac{1}{2}$.

Fig. 10.— $\times 1$ should read $\times \frac{1}{2}$.

Fig. 12.—Should read *Tetragraptus acclinans* $\times 1$.

Fig. 13b.— $\times 1$ should read $\times \frac{1}{2}$.

Page 41, Figs. 31, 38, 39, 44, 54, 55, 56, 70, 71, 74, 79, 80, 81:

$\times 1$ should read $\times 2$.

Page 41:

Fig. 89.— $\times 2$ should read $\times 4$.

Fig. 95.— $\times 2$ should read $\times 4$.

Figs. 101, 102, 103, 104, 105.— $\times 1$ should read $\times 2$.

Page 42:

Figs. 124, 126a, 127, 128, 129, 135.— $\times 1$ should read $\times 2$.

Fig. 143.—Magnification $\times 4$ for both figures.

Figs. 144, 145, 146, 147, 149, 153, 154, 155, 159, 160, 161.— $\times 1$ should read $\times 2$.

Fig. 162.— $\times 2$ should read $\times 4$.

Figs. 163, 165, 174, 179.— $\times 1$ should read $\times 2$.

Fig. 180.— $\times 1$ read $\times 2$ and $\times 4$.

Plates:

Fig. 74.— $\times 2$.

Fig. 180a.— $\times 2$.

Fig. 180b.— $\times 4$.

Fig. 192.— $\times 4$.

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